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STRATIGRAPHY, SEDIMENTOLOGY, AND PALYNOLOGY OF THE CRETACEOUS (ALBIAN) BEAVER MINES, MILL CREEK, AND CROWSNEST FORMATIONS (BLAIRMORE GROUP) OF SOUTHWESTERN ALBERTA

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Cover Illustration
Exposure of coarsening-upward coastal Lynx Creek Member (Mill Creek Formation) at Lynx Creek. Access is via Alberta Forestry Service Lynx Creek Campground (GSCC photo 4705-2).

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STRATIGRAPHY, SEDIMENTOLOGY, AND PALYNOLOGY OF THE CRETACEOUS (ALBIAN) BEAVER MINES, MILL CREEK, AND CROWSNEST FORMATIONS (BLAIRMORE GROUP) OF SOUTHWESTERN ALBERTA

Abstract

A sedimentological and palynological re-examination of the Cretaceous upper Beaver Mines, Mill Creek, and Crowsnest formations was carried out in the Rocky Mountain Foothills and eastern Front Ranges in southwestern Alberta. The result is a refinement of existing stratigraphy and a new palynological zonation, providing finer paleoecological and biostratigraphic resolution of local and regional events. The palynomorph assemblages recovered for this study form one of the largest and most comprehensive collections of Albian taxa in Western Canada. Two new stratigraphic units are identified within the Mill Creek Formation: the marine to brackish-water Lynx Creek Member, and the nonmarine Bruin Creek Member. The base of the Bruin Creek Member is bounded by a regional low-angle unconformity.

Résumé

La partie supérieure des formations de Beaver Mines, de Mill Creek et de Crowsnest reposant dans les Foothills des Rocheuses et l'est des Front Ranges du sud-ouest de l'Alberta a fait l'objet d'un nouvel examen sédimentologique et palynologique. Il en résulte une stratigraphie plus détaillée et une nouvelle zonation palynologique, permettant une résolution paléoécologique et biostratigraphique plus fine des événements locaux et régionaux. Les assemblages de palynomorphes récupérés dans le cadre de cette étude constituent l'une des collections les plus vastes et les plus exhaustives de taxons albiens de l'Ouest canadien. On a délimité deux nouvelles unités stratigraphiques dans la Formation de Mill Creek : le Membre de Lynx Creek déposé dans des eaux marines à saumâtres et le Membre de Bruin Creek déposé dans des milieux non marins. La base du Membre de Bruin Creek est limitée par une discordance régionale faiblement inclinée.

Summary

The purpose of this paper is to better define the existing stratigraphy of the upper Beaver Mines and Mill Creek formations, and to provide a palynological framework for the Rocky Mountain Foothills in southern Alberta. Historically, there has been only minimal recovery of marine and nonmarine fauna from the upper Beaver Mines and Mill Creek formations, making biostratigraphic resolution difficult. However, the strata provide an excellent opportunity to study well-preserved palynoflora and dinoflagellates, and the resulting data permit finer paleoecological and biostratigraphic resolution of local and regional events. When palynological data are integrated with lithological and sedimentological descriptions, regional sedimentological interpretations may be related to tectonic events that occurred in the Cordillera farther west. The lithostratigraphic descriptions are based on the examination of 13 outcrop sections from the Rocky Mountain Foothills in the vicinity of the Crowsnest Pass and Oldman River.

Palynomorph assemblages recovered for this study form one of the largest and most comprehensive collections of Albian taxa in Western Canada. These rocks contain 111 species of spores, 28 gymnosperms and 50 angiosperms (18 monocots and 32 dicots). Other fossils include 8 species of fungi, 34 dinoflagellates, 6 chlorophytes, 6 praesinophytes, and 5 acritarchs (Appendix 1). Fossil assemblages are so rich in angiospermous pollen species that the standard literature used for identifying and correlating Alberta palynomorphs is of little direct use in biostratigraphy; studies from elsewhere in North America had to be examined to achieve any reasonable sense of the biostratigraphy of these rocks.

The result is a refinement of the existing stratigraphy and a new palynological zonation, which provides a finer paleoecological and biostratigraphic resolution of local and regional events. Two new stratigraphic units are identified within the Mill Creek Formation: the marine to brackish-water Lynx Creek Member, and the

nonmarine Bruin Creek Member. The base of the Bruin Creek Member is bounded by a regional low-angle unconformity.

Angiosperms from the top of the Beaver Mines Formation are thought to be late Middle Albian in age. Our samples of the upper Beaver Mines Formation indicate nonmarine and brackish-water deposits of the Early and Middle Albian. A prolonged episode of nondeposition and soil development separates the Early and Middle Albian deposits of the Beaver Mines Formation.

The Lynx Creek Member contains marine to brackish-water palynomorphs, microfossils, macrofossils, and trace fossils. Sedimentary structures and fossils indicate that Lynx Creek Member strata probably formed in shallow-marine and shoreline environments. The palynomorphs and microfossils suggest that correlative horizons in Western Canada are the upper Hulcross Formation and upper Harmon and Cadotte members of the Peace River Formation of northeastern British Columbia and northwestern Alberta. The Lynx Creek Member may be correlative with strata of the Colony Formation of Saskatchewan and central Alberta. These rocks reaffirm the inference that the uppermost Beaver Mines and Lynx Creek Member strata are conformable and of late Middle Albian and perhaps earliest Late Albian age.

The Bruin Creek Member occurs throughout the Rocky Mountain Foothills from the Carbondale River north to the Livingstone River. Reconnaissance observations indicate that the member may extend farther north to the Bow River, and possibly beyond. Subsurface equivalents of the Bruin Creek Member in southwestern Alberta include the marine and nonmarine strata of the Bow Island Formation. The McDougall-Segur Conglomerate is an informal term applied to Bruin Creek Member strata. It consists of laterally discontinuous beds of conglomerate up to 30 m thick and 3 km wide. Internally, McDougall-Segur beds are rich in igneous and volcanic clasts with lesser amounts of chert and quartzite set in a medium-grained, greenish grey, arkosic matrix. The Bruin Creek Member is early Late Albian. Strata above the basal sandstone exhibit a marked increase in rock fragment content, and the quartz and chert content decreases. Siltstone and clay represent floodplain and overbank deposits that were pedogenically altered. Sandstone was deposited by high-sinuosity meandering rivers. The water table was probably relatively low, or fluctuated, because only minimal organic matter has been preserved. The igneous clast conglomerate was deposited in braided rivers within incised valleys.

Unconformities within the Beaver Mines and Mill Creek formations are thought to have formed during a period of time when other significant unconformities developed elsewhere in western North America. However, the interregional relationships of these unconformities are not well understood. The results of this study provide the first documentation of a Middle Albian marine incursion into the Foothills of southwestern Alberta (Lynx Creek) which may have implications for hydrocarbon exploration, and in particular, for geodynamic modelling and correlating strata. Finally, because of the historic interest in gold from the Crowsnest Pass area, assay results from the upper Blairmore Group are presented to provide background information for potential mineral prospecting.

The Crowsnest Pass–Oldman River area is reputed to have encompassed the legendary lost Lemon Gold Mine. The source of the alleged gold deposits has been attributed to gravels in modern streams in this area, paleo-placer deposits, and more recently, the volcanic rocks of the Crowsnest Formation. The McDougall-Segur Conglomerate has gold values ranging from 10 to 80 ppb. Clasts in the McDougall-Segur Conglomerate were derived from Mesozoic volcanic and plutonic rocks in the Omineca Crystalline Belt of central British Columbia, specifically the Nelson and Kaskanax batholiths. The batholiths and surrounding regions have had a long history of extensive gold–quartz vein deposits and were a likely source of placer material.

Sommaire

Le présent document vise à mieux définir la stratigraphie actuelle de la partie supérieure des formations de Beaver Mines et de Mill Creek et d'établir un cadre palynologique pour les Foothills des Rocheuses dans le sud de l'Alberta. La récupération de fossiles faunistiques d'origine marine et non marine dans la partie supérieure de ces deux formations ayant été jusqu'à maintenant très faible, il est difficile d'établir un profil

biostratigraphique. Cependant, les strates offrent une excellente occasion d'étudier la palynoflore et les dinoflagellés qui ont été bien conservés et d'affiner ainsi la résolution paléoécologique et biostratigraphique des phénomènes locaux et régionaux. Lorsqu'on intègre les données palynologiques aux descriptions lithologiques et sédimentologiques, il est alors possible de corréler les interprétations sédimentologiques régionales avec les épisodes tectoniques qui se sont produits plus à l'ouest dans la Cordillère. Les descriptions lithostratigraphiques sont basées sur l'examen de 13 coupes affleurant dans les Foothills des Rocheuses dans les environs du col Crowsnest et de la rivière Oldman.

Les assemblages de palynomorphes récupérés pour cette étude constituent l'une des collections de taxons albiens les plus vastes et les plus exhaustives de l'Ouest canadien. Ces roches renferment 111 espèces de spores, 28 gymnospermes et 50 angiospermes (18 monocotylédones et 32 dicotylédones). Les autres fossiles incluent 8 espèces de champignons, 34 dinoflagellés, 6 chlorophytes, 6 praesinophytes et 5 acritarches (annexe 1). Les pollens d'angiospermes sont si abondants dans les assemblages de fossiles que la documentation habituellement utilisée pour identifier et corréler les palynomorphes de l'Alberta sont dans ce cas de faible utilité à des fins de biostratigraphie; il a donc fallu examiner les études portant sur d'autres sites en Amérique du Nord pour aboutir à une biostratigraphie quelque peu logique de ces roches.

On obtient une stratigraphie plus précise et une nouvelle zonation palynologique, donc une résolution plus fine de la paléoécologie et de la biostratigraphie des événements locaux et régionaux. Deux nouvelles unités stratigraphiques sont délimitées dans la Formation de Mill Creek : le Membre de Lynx Creek déposé dans des eaux marines à saumâtres et le Membre de Bruin Creek déposé dans des milieux non marins. La base du Membre de Bruin Creek est limitée par une discordance régionale faiblement inclinée.

Les angiospermes du sommet de la Formation de Beaver Mines dateraient de la fin de l'Albien moyen. Les échantillons provenant de la partie supérieure de la Formation de Beaver Mines sont des dépôts de milieux non marins et d'eaux saumâtres de l'Albien précoce et moyen. Les dépôts de l'Albien précoce et moyen de la Formation de Beaver Mines sont séparés par un épisode prolongé de pédogenèse pendant laquelle il n'y a pas eu de sédimentation.

Le Membre de Lynx Creek contient des palynomorphes, des microfossiles, des macrofossiles et des ichnofossiles d'eaux marines à saumâtres. D'après les structures sédimentaires et les fossiles, les strates du Membre de Lynx Creek se sont vraisemblablement formées dans des milieux épicontinentaux et littoraux. D'après les palynomorphes et les microfossiles étudiés, les horizons corrélatifs dans l'Ouest canadien se trouvent être dans la partie supérieure de la Formation de Hulcross et la partie supérieure des membres de Harmon et de Cadotte de la Formation de Peace River dans le nord-est de la Colombie-Britannique et le nord-ouest de l'Alberta. Il existe peut-être une corrélation entre le Membre de Lynx Creek et les strates de la Formation de Colony en Saskatchewan et dans le centre de l'Alberta. Ces roches corroborent l'hypothèse selon laquelle les strates sommitales de la Formation de Beaver Mines et du Membre de Lynx Creek seraient concordantes et remonteraient à la fin de l'Albien moyen et peut-être du tout début de l'Albien tardif.

Le Membre de Bruin Creek est présent partout dans les Foothills des Rocheuses entre la rivière Carbondale et la rivière Livingstone au nord. Selon des observations de reconnaissance, il pourrait s'étendre jusqu'à la rivière Bow plus au nord, et même au-delà. Dans le sud-ouest de l'Alberta, les roches sédimentaires marines et non marines de la Formation de Bow Island sont des équivalents subsuperficiels du Membre de Bruin Creek. Le conglomérat de McDougall–Segur est le nom informel donné aux strates du Membre de Bruin Creek qui comportent des lits latéralement discontinus de conglomérat mesurant jusqu'à 30 m d'épaisseur et 3 km de largeur. Les lits du conglomérat de McDougall–Segur contiennent des clastes ignés et volcaniques abondants et, en proportions moindres, du chert et du quartzite dans une matrice arkosique gris verdâtre à grain moyen. Le Membre de Bruin Creek date du début de l'Albien tardif. La teneur en fragments lithologiques augmente nettement dans les roches sédimentaires situées au-dessus du grès de base alors que la teneur en quartz et chert diminue. Le siltstone et l'argile représentent des dépôts de plaine d'inondation et de débordement dont les sols ont été perturbés. Le grès a été déposé par des cours d'eau très sinueux. Ou la nappe phréatique était probablement relativement basse ou elle a subi des fluctuations, si l'on se base sur la très faible quantité de matières organiques qui ont été conservées. Le conglomérat à clastes ignés a été déposé dans des cours d'eau anastomosés traversant des vallées encaissées.

Les discordances au sein des formations de Beaver Mines et de Mill Creek dateraient de la même époque que d'autres discordances importantes dans l'ouest de l'Amérique du Nord. Cependant, on n'a pas tout à fait élucidé les liens qui existent entre ces discordances de régions différentes. Les résultats de la présente étude permettent de documenter pour la première fois une incursion marine durant l'Albien moyen dans les Foothills du sud-ouest de l'Alberta (Lynx Creek) et ils pourraient être utiles pour l'exploration d'hydrocarbures et, notamment, pour la modélisation géodynamique. Enfin, étant donné l'attrait qu'a suscité l'or dans le passé dans la région du col Crowsnest, les résultats d'analyses sur la partie supérieure du Groupe de Blairmore constituent des données de base pour la prospection minérale.

La région du col Crowsnest et de la rivière Oldman est connue pour l'ancienne mine d'or Lemon. On a attribué l'origine de l'or à des graviers de cours d'eau modernes traversant la région, à des gisements paléoplacériens et, plus récemment, aux roches volcaniques de la Formation de Crowsnest. La teneur en or du conglomérat de McDougall–Segur varie entre 10 et 80 ppb. Les clastes du conglomérat de McDougall–Segur sont dérivés de roches volcaniques et plutoniques mésozoïques dans le domaine cristallin d'Omineca dans le centre de la Colombie-Britannique, soit des batholites de Nelson et de Kaskanax. C'est dans ces batholites et les régions avoisinantes que l'on a trouvé des gîtes filoniens de quartz aurifère et ils sont peut-être une source de matériaux placériens.

INTRODUCTION

Outcrops of the Albian Blairmore Group in southwestern Alberta have long been a source of geological fascination. The Crowsnest Formation of the Blairmore Group, which was first recognized by G.M. Dawson in 1886, is one of the few, rare occurrences of extrusive volcanic deposits within Mesozoic strata of the Foothills and Rocky Mountains of Western Canada east of the Rocky Mountain Trench. The Mill Creek and Beaver Mines formations of the Blairmore Group contain distinctly different floral successions (J.W. Dawson, 1886; Berry, 1929 a, b; Bell, 1956; Mellon, 1967). The Beaver Mines Formation is characterized by abundant ferns, cycadophytes and conifers, with only rare angiosperms, whereas the Mill Creek Formation contains abundant angiosperms.

The legendary lost Lemon Gold Mine is reputed to have been in the Crowsnest Pass–Oldman River area (Fig. 1; Riley et al., 1968). The source of the alleged gold deposits has been attributed to gravels in modern streams, paleoplacer deposits, and more recently, from the volcanic rocks of the Crowsnest Formation.

In this paper, the upper part of the Mill Creek Formation is shown to be the outcrop equivalent of subsurface reservoirs found in the Viking and Bow Island formations, which contain in excess of 10,199.3 x 10^9 cubic feet of natural gas and 501.9 x 10^6 barrels of oil (Porter, 1992). As such, the outcrop expression of sandstone and conglomerate of the Mill Creek Formation may provide an indication of new hydrocarbon reservoir trends and models in the subsurface.

The purpose of this study was to refine the existing stratigraphic framework of the upper Beaver Mines and Mill Creek formations, and to provide a palynological framework for the Rocky Mountain Foothills in southern Alberta. Historically, there has been only minimal recovery of marine and nonmarine fauna from the upper Beaver Mines and Mill Creek formations, making biostratigraphic resolution difficult. However, since these strata are thermally immature, with vitrinite reflectances of coal spar in the order of 0.6 to 0.8 R_o (W. Kalkreuth, pers. comm., 1990) the strata provide an excellent opportunity to study well-preserved palynoflora and dinoflagellates. These data will provide finer paleoecological and biostratigraphic resolution of local and regional events. When palynological data are integrated with lithological and sedimentological descriptions, regional sedimentological interpretations may be related to tectonic events that occurred in the Cordillera farther west.

Unconformities within the Beaver Mines and Mill Creek formations formed during a period of time when other significant unconformities were developing elsewhere in western North America (Weimer, 1983; Aubrey, 1989; Stelck and Leckie, 1990; Leckie and Singh, 1991; Dolson et al., 1991). However, the interregional relationships of these unconformities are not well understood. In this paper, we provide the first documentation of a Middle Albian marine incursion into the Foothills of southwestern Alberta (Lynx Creek Member, Fig. 2), which may have implications for hydrocarbon exploration, and in particular, for geodynamic modelling and correlating strata. Finally, because of the historical interest in gold from the Crowsnest Pass area, assay results from the upper Blairmore Group are presented to provide background information for potential mineral prospecting.

Palynomorph assemblages recovered for this study form one of the largest and most comprehensive collections of Albian taxa in Western Canada. These rocks contain 111 species of spores, 28 gymnosperms, and 50 angiosperms (18 monocots and 32 dicots). Other fossils include eight species of fungi, 34 dinoflagellates, 6 chlorophytes, six praesinophytes, and five acritarchs (Appendix 1). Fossil assemblages are so rich in angiospermous pollen species that the standard literature used for identifying and correlating Alberta palynomorphs (Norris 1967; Singh 1971; Playford 1971) is of little direct use in biostratigraphy; studies from elsewhere in North America (Doyle and Robbins 1977; Wingate 1980; Ward 1986) must be examined to achieve any reasonable sense of the biostratigraphy of these rocks.

Previous work

The economic importance of Lower Cretaceous rocks of the southern Alberta Foothills has attracted geologists for more than 100 years. G.M. Dawson (1886) separated a lower coal-bearing series of sandstones and shales (the "Kootanie series") from an upper, barren interval (the "Dakota series") covered with volcanigenic tuff and agglomerate (Fig. 3). Plant fossils in these rocks led J.W. Dawson (1886) to divide the strata into three series based on recognition of the flora; these series were a lower, non-dicotyledonous flora ("Kootanie series"), an "Intermediate series" with some dicotyledonous remains, and an upper dicotyledonous flora called the "Mill Creek series".

Detailed mapping by Leach (1912, 1914) and Rose (1917) led to the formal division of the Kootenay and Blairmore formations and the Crowsnest Volcanics (Fig. 3). Berry (1929a) and McLearn (1929a, b) examined plants and invertebrates in these rocks and placed the Kootenay in the Barremian, and the Blairmore in the Aptian–Albian.

As the focus for geological exploration and research switched to the search for hydrocarbons beneath the Interior Plains, drillers working the Cretaceous strata of the subsurface of southern Alberta coined a plethora of names to describe different productive sandstone bodies in the

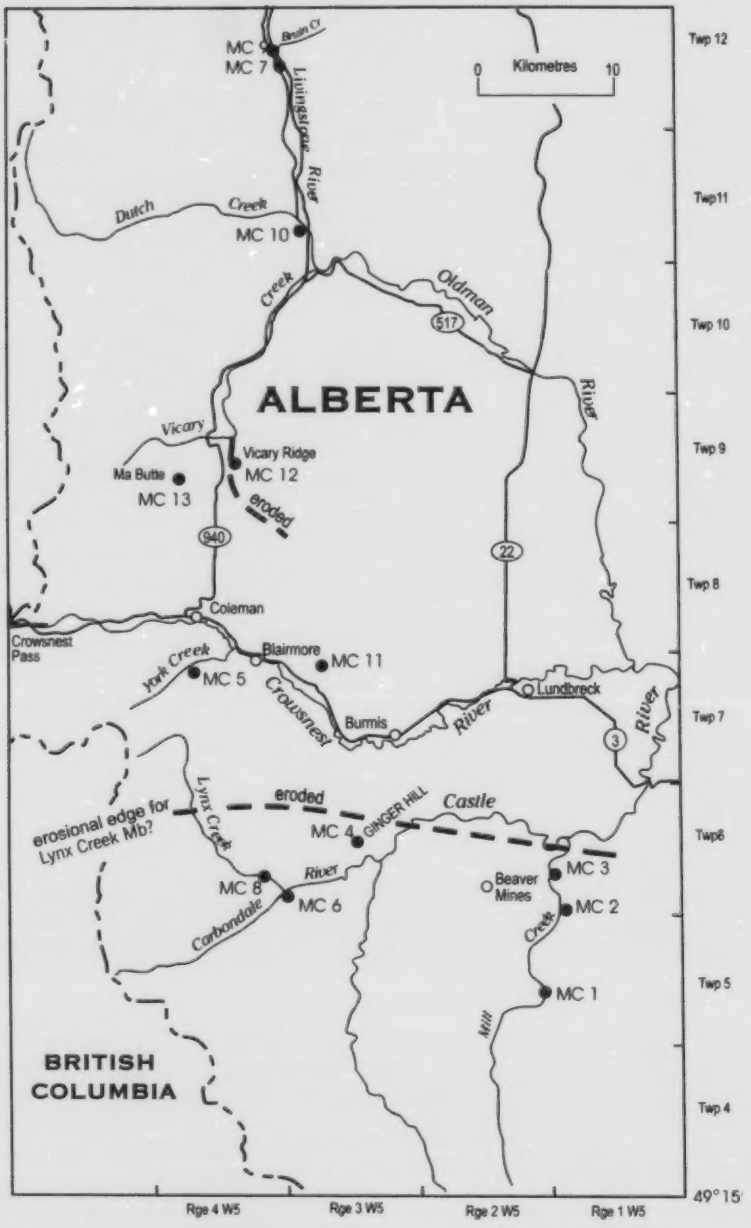


Figure 1. *Location map for measured sections. Dashed lines show possible erosional edge for Lynx Creek Member. Measured sections are labeled MC 1, MC 2, etc.*

Blairmore Formation. Among these names were the Dalhousie Sandstone, Cadomin Conglomerate, Home Sandstone, Calcareous Member, Glauconitic Member, McDougall-Segur Sand and Stockmans Sand (Hume, 1930, 1938, 1939). Little consistency or sense could be made of these local names until some regional assessment was completed.

Douglas (1950) and Glaister (1959) formally recognized a tripartite division of the Blairmore Group (Fig. 3). Cherty conglomerate and sandstone of the Cadomin Formation rest unconformably upon Kootenay Formation coal-bearing strata. The Dalhousie Formation is a chert and quartz sandstone overlying the conglomerate of the Cadomin Formation (Leckie and Cheel, 1997). The Dalhousie

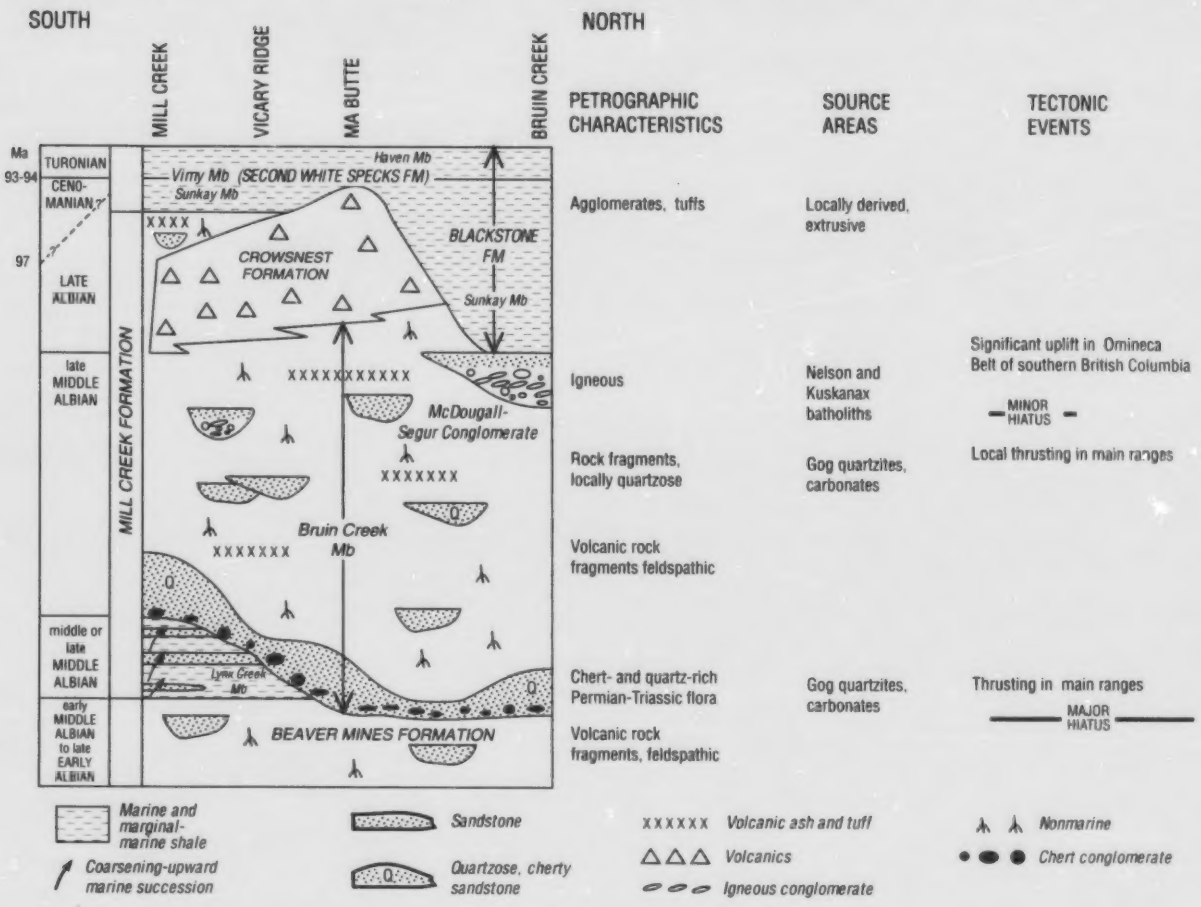


Figure 2. *Schematic south-to-north cross-section showing the revised stratigraphy of the upper Blairmore Group along the Rocky Mountain Foothills in southwestern Alberta.*

Formation is overlain by lower Blairmore, white to grey sandstone and shale, which become calcareous toward the top (Gladstone Formation and Calcareous Member, Fig. 3). Upper Blairmore quartzose sandstone beds overlying the Calcareous Member were previously called the Home Sand or the Glauconitic Sand. The remainder of the upper Blairmore in southern Alberta is essentially feldspathic sandstone and grey-green and maroon shale with some cherty sandstone near the top (Douglas, 1950).

Mellon and Wall (1961; 1963) recognized lithological and paleontological breaks in the Blairmore Group (Fig. 3, 4). They proposed a middle Blairmore interval for feldspathic rocks lying above the Calcareous Member and below a prominent unconformity that separates upper Blairmore cherty and volcaniclastic rocks containing Dawson's Mill Creek angiosperm flora. Mellon (1967) formalized this stratigraphy by erecting the Beaver Mines Formation for the middle Blairmore and the Mill Creek Formation for the upper Blairmore Group (Fig. 3). Mill Creek strata included the formal definition of the Crowsnest Member as a volcaniclastic interval at the top of the Mill Creek Formation.

An igneous pebble conglomerate in the upper Beaver Mines and Mill Creek formations occurs in several places along the length of the Rocky Mountain Foothills. This conglomerate was previously called the McDougall-Segur Conglomerate (Mellon, 1967; Norris, 1964). The conglomerate occurs at different stratigraphic positions; consequently, the name has not been properly applied and should be abandoned (Leckie and Krystinik, 1995). Crowsnest Formation volcanics or volcaniclastic siltstone and tuffaceous beds mark either a sharp or a gradational contact at the top of the Blairmore Group (Douglas 1950).

The lithostratigraphic nomenclature for the beds lying above the Beaver Mines Formation has been and remains a

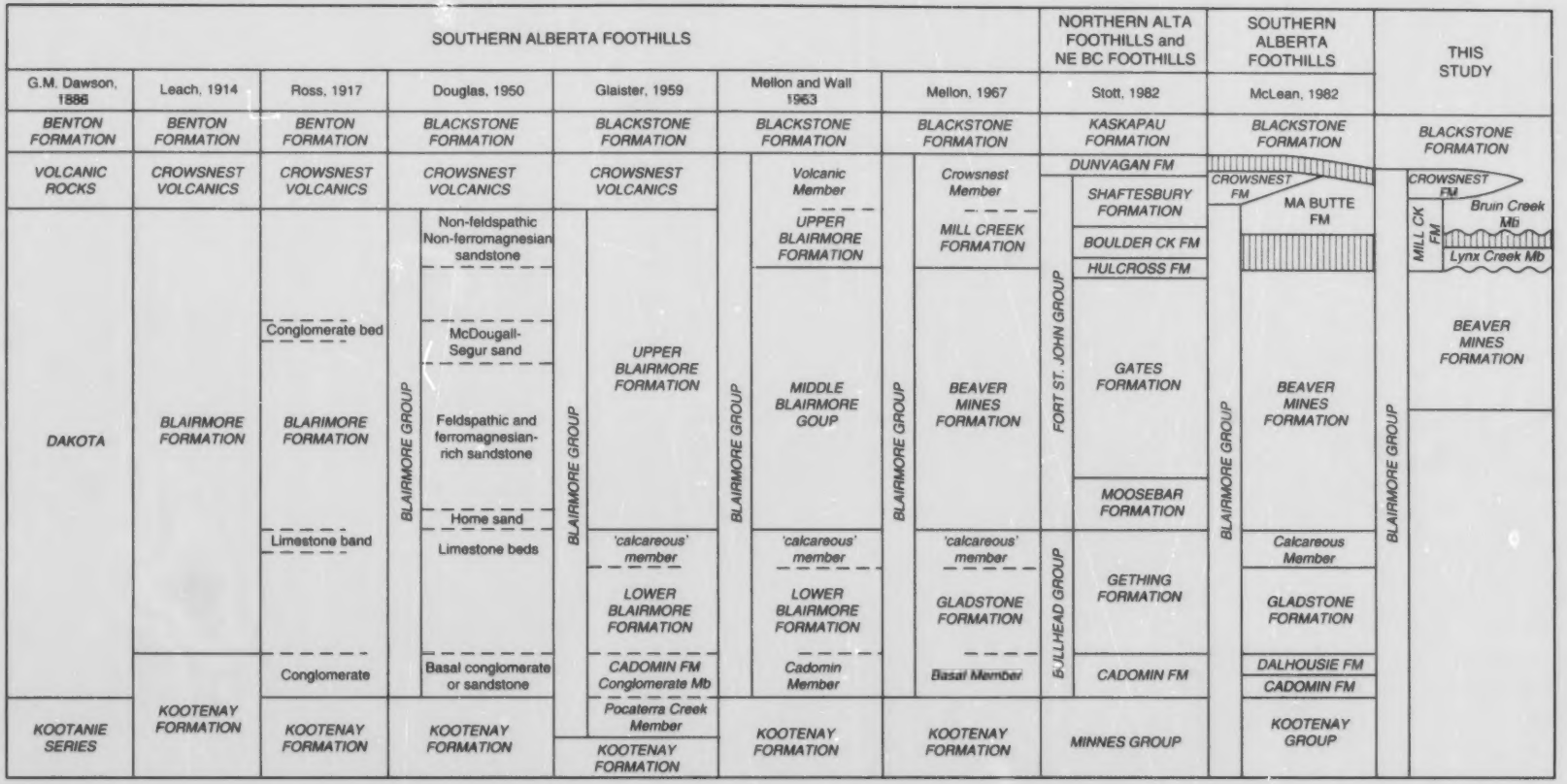


Figure 3. *Historical correlation chart (derived from McLean, 1982, with modifications from Leckie and Cheel, 1997).*

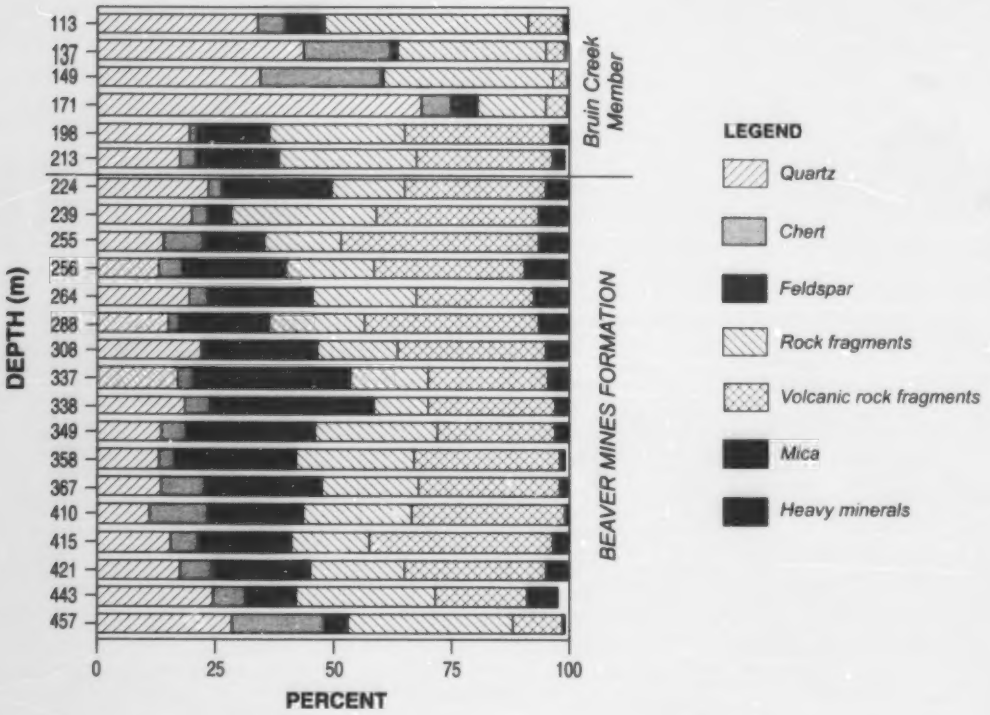


Figure 4. *Petrography of strata of the Beaver Mines Formation and Bruin Creek Member of the Mill Creek Formation (data from Mellon, 1967).*

source of controversy. Douglas (1950) recognized the lithological differences between the lower, feldspathic (now Beaver Mines Formation) and upper, non-feldspathic sandstones (now basal portion of the Mill Creek Formation) within the Blairmore Group. Volcaniclastic deposits above non-feldspathic sandstone were informally defined as the Crowsnest formation as early as 1886 (G.M. Dawson, 1886). Mellon (1967) applied these lithological distinctions to formally define the Beaver Mines and Mill Creek formations. According to Mellon (1967), the Mill Creek type section consists of two distinctive lithologies: an 87 m thick, lower succession of quartzose, cherty sandstone and varicoloured shale; and an upper, in part laterally correlative, 80 m thick succession of pyroclastic beds, the Crowsnest Member. At the type locality of the Mill Creek Formation, the lower contact with the top of the Beaver Mines Formation is marked by a sharp, yet conformable change from varicoloured mudstone and feldspathic sandstone to 25 m of grey siltstone, black shale, and quartzose sandstone beds (Mellon, 1967, fig. 5); 62 m of cherty sandstone and varicoloured mudstone form the remainder of the lower part of the Mill Creek Formation (Fig. 3). Mellon (1967) recognized the fundamentally different nature of what we now call the Lynx Creek Member, but could not, at that early date, discern the age differences in his Mill Creek Formation.

McLean (1982) established the Ma Butte Formation for "quartzose" strata making up the lower part of Mellon's Mill Creek Formation. McLean proposed to raise the volcanic rocks of Mellon's Crowsnest Member to formation status (a transfer already completed by others) and considered the Mill Creek Formation to be redundant on the grounds that it was a sedimentological and biostratigraphic unit rather than a lithological unit (McLean, 1982; p. 4). The confusion created by McLean's abandonment of a properly defined formation (Mellon, 1967) so that the Crowsnest Member might be raised to formation status warrants keeping the Mill Creek as a valid stratigraphic unit. McLean's lithostratigraphic nomenclature should be abandoned. The term Mill Creek, although initially used in a biostratigraphic sense, is accepted and legally defined terminology and has been used to describe these rocks since 1886 (J.M. Dawson, 1886; Mellon, 1967).

The Crowsnest interval, given formation status by Norris (1967) and Price (1962), occurs above Blairmore strata. Mellon (1967), in recognition of regional stratigraphic relationships, assigned the Crowsnest Volcanics to the Blairmore Group but reduced it to member status. Adair (1986) proposed that the Crowsnest interval be returned to its former rank as formation. We follow accepted conventions but keep the Crowsnest Formation as the rock

unit lying above our newly defined Bruin Creek Member and within the Blairmore Group.

In this study, the mixed quartzose sandstone and mudstone, originally identified by Mellon (1967) from the basal part of the Mill Creek Formation, are recognized as a distinctive lithological unit herein called the Lynx Creek Member (Fig. 2, 3). Lynx Creek Member strata lie conformably upon the Beaver Mines Formation. A regional low-angle unconformity separates the quartzose Lynx Creek Member from overlying, more cherty Mill Creek strata, herein called the Bruin Creek Member. Locally, this unconformity is manifested by a prominent scour surface with thick bedded cherty sandstone above.

Acknowledgments

The stratigraphy and sedimentology is based on fieldwork by Leckie between 1989 and 1996; palynology is by Burden. These studies were supplemented by unpublished macro- and microfossil reports by J.W. Haggart and J.H. Wall and by commercial geochemical asseys carried out by Loring Laboratories of Calgary, Alberta. J.H. Wall, A.R. Sweet and D.J. McIntyre provided advice on the interpretation of paleontological data. Logistical facilities at the Geological Survey of Canada (Calgary) were provided to Burden during his sabbatical in 1990. Ross Campbell, Angus Leech and Jessica Leech were field assistants. Aspects of the geology have been discussed with Lee Krystinik and John Bloch. The manuscript benefited from reviews by John Wall and Art Sweet.

All outcrop samples used in this study and all palynological slides, including illustrated material, are stored at the Geological Survey of Canada, Calgary, Alberta.

REGIONAL GEOLOGICAL SETTING

The western North American foreland basin, into which the Blairmore Group was deposited, was an elongate trough that developed between the eastern flanks of the ancestral Rocky Mountains and the stable interior platform of the Canadian Shield. At its maximum extent, the foreland basin was more than 6000 km long and up to 1600 km wide, stretching from the Arctic Ocean to the Gulf of Mexico and extending from westernmost Ontario to central British Columbia.

The paleogeographic evolution and tectonic history of the Western Canada Sedimentary Basin and Rocky Mountain Belt are discussed elsewhere in several publications (e.g., Porter et al., 1981; Fermor and Moffat, 1992; Price, 1981; Monger et al., 1982; Leckie and Smith, 1992; McMechan and Thompson, 1993).

STRATIGRAPHY

The lithostratigraphic descriptions of the Mill Creek Formation are based on the examination of 13 outcrop sections from the Rocky Mountain Foothills in the vicinity of the Crowsnest Pass and Oldman River (Fig. 1, Table 1). Selected measured sections are shown in Figure 5. Detailed sections of all type and measured sections are shown within the text. Detailed descriptions of all other measured sections are found in Appendix 2.

Beaver Mines Formation

Definition, distribution, and description

The Beaver Mines Formation is the lowest unit examined in this study, and only beds in the upper portion of the formation were sampled. On the Carbondale River (MC 6, Fig. 1), 138 m of upper Beaver Mines strata were measured (Fig. 5); at Mill Creek (MC 1, Fig. 1), 103.6 m were measured (Fig. 5, 6). Mellon (1967) described the Beaver Mines Formation as those strata that lie above the limestone beds of the Gladstone Formation. Detailed description of the Beaver Mines Formation in Mellon (1967) indicates that thicknesses range from 253 m to 366 m. Lithologies consist of "interbedded green, fine-grained, crossbedded, feldspathic sandstone, dark green laminated siltstone and blocky, varicoloured shale (mudstone), the sandstones becoming thinner and finer-grained towards the top of the formation" (Mellon 1967; p. 20). This is in sharp contrast to the lower part of the Beaver Mines, which is medium- to coarse-grained feldspathic sandstone with exotic volcanic pebbles and thin beds of dark green-grey siltstone (Mellon, 1967). The lower contact of the Beaver Mines Formation is sharp and overlies dark, silty limestone beds of the Calcareous Member of the Gladstone Formation.

Lithology and sedimentology

The upper Beaver Mines Formation consists of interbedded sandstone, siltstone, and shale containing abundant in situ vertical roots, pedogenic slickensides and peds. Peds vary from a crumb stucture to 1 to 2 cm-in-diameter blocky or columnar forms. Colours vary from olive green to red, and to variegated greens and reds. Sandstone beds are decimetres to 6 m thick and fine to medium grained. Individual sandstones are sharp based; they may contain intraformational shale clasts and typically fine upward (Fig. 7a). Because of the nature of the weathering, sedimentary structures are generally difficult to discern.

Calcite nodules in calcareous siltstone occur near the top of the Beaver Mines Formation at Mill Creek (MC 1, 93 m

Table 1
Location of outcrops discussed in text and in Appendix 2

Section name	Location	Location	Directions
MC 1	Mill Creek, south	49° 22′ 58″ N, 114° 08′ 15″ W Tp 5, Rge 2W5	start a few hundred metres north of confluence of Whitney Creek and Mill Creek; on property of Pincher Creek Ranches
MC 2	Mill Creek, centre	49° 26′ 58″ N, 114° 07′ 31″ W Tp 6, Rge 1W5	access to section via the farm of Jack Morgan, Pincher Creek
MC 3	Mill Creek, bridge section	49° 27′ 51″ N, 114° 07′ 57″ W Tp 6, Rge 1W5	highway section along Mill Creek; section begins south of bridge on property of Bert Link
MC 4	Ginger Hill	49° 28′ 56″ N, 114° 19′ 55″ W Tp 5, Rge 2W5	Ginger Hill, southwest side; on ranch of Judge McLaughlin, Pincher Creek
MC 5	York Creek	49° 35′ 55″ N, 114° 30′ 30″ W Tp 7, Rge 4W5	isolated outcrop of igneous-pebble conglomerate; cannot be put in context
MC 6	Carbondale River	49° 27′ 06″ N, 114° 24′ 32″ W Tp 5, Rge 2W5	section begins on river where access can be attained at the Province of Alberta Lynx Creek Recreation Area
MC 7 MC 9	at and south of junction of Livingstone River and Bruin Creek	50° 00′ 25″ N, 114° 20′ 54″ W Tp 12, Rge 4W5	composite section constructed along river
MC 8	Lynx Creek	49° 27′ 29″ N, 114° 25′ 02″ W Tp 5, Rge 2W5	upstream from the junction of Lynx Creek and the Carbondale River; at the waterfall
MC 10	Dutch Creek	49° 54′ 20″ N, 114° 24′ 00″ W Tp 5, Rge 2W5	on Dutch Creek about 2 km from the confluence with Oldman River
MC 11	Frank Slide Interpretive Centre	49° 36′ 21″ N, 114° 24′ 25″ W Tp 7, Rge 3W5	composite section constructed along road to Centre and above the parking lot
MC 12	Vicary Ridge	49° 44′ 10″ N, 114° 27′ 15″ W Tp 9, Rge 4W5	near the headwaters of Vicary Creek, south side of ridge; get access from the 6-14-9-4 W5 well site
MC 13	Ma Butte	49° 44′ 00″ N 114° 31′ 00″ W Tp 9, Rge 4W5	access by hiking trail

and 102 m, Fig. 6, 7b). The nodules are well rounded, 0.5 to 6 cm in diameter, and some occur as vertical rhizocretions (Fig. 7b).

At Ma Butte (MC 13, 75.8–101.6 m, Fig. 8), there is a succession of black, carbonaceous shale that coarsens upward to siltstone and then rippled sandstone. There are abundant delicate plant impressions and comminuted carbonaceous debris. There are no pedogenic indicators within this 25.8 m thick interval, which is unusually thick for the upper Beaver Mines Formation. Roots, peds and slickensides occur at the top of the succession.

Paleocurrent indicators were observed at only a few outcrops. At Vicary Ridge (MC 12, Fig. 9), trough-crossbeds from fining-upward sandstone beds in point-bar deposits indicate paleoflow toward the northeast. At Ma Butte, grooves from the base of fluvial sandstone and parting lineations indicate paleoflows trending north–south.

Age and paleontology

Distinctive palynomorph assemblages occur in the sampled strata of the upper parts of the Beaver Mines Formation. The lowest sampled beds of the upper Beaver Mines Formation on Carbondale River (C-179820–C-179824), 100 to 130 m below the contact with the Mill Creek Formation, contain diverse spore and gymnosperm pollen assemblages with a small number of marine algae (Fig. 10). Taxa recovered include commonly observed spores *Impardecispora marylandensis*, *Concavissimisporites variverrucatus*, *Verrucosisporites rotundus*, *Cicatricosisporites minor*, *Appendicisporites unicus* (with short processes), *Plicatella crimenensis*, *Stoverisporites lunaris* and *Foveotriletes subtriangularis*, gymnosperms *Alisporites bilateralis*, *Vitreisporites pallidus*, *Eucommidites* sp. and *Classopollis* sp. No angiosperm pollen have been identified from these beds. Algae, *Chomotriletes minor*, *Pterospermella harti*, *Nyktericysta davisii* and *Oligosphaeridium* sp. are rare in

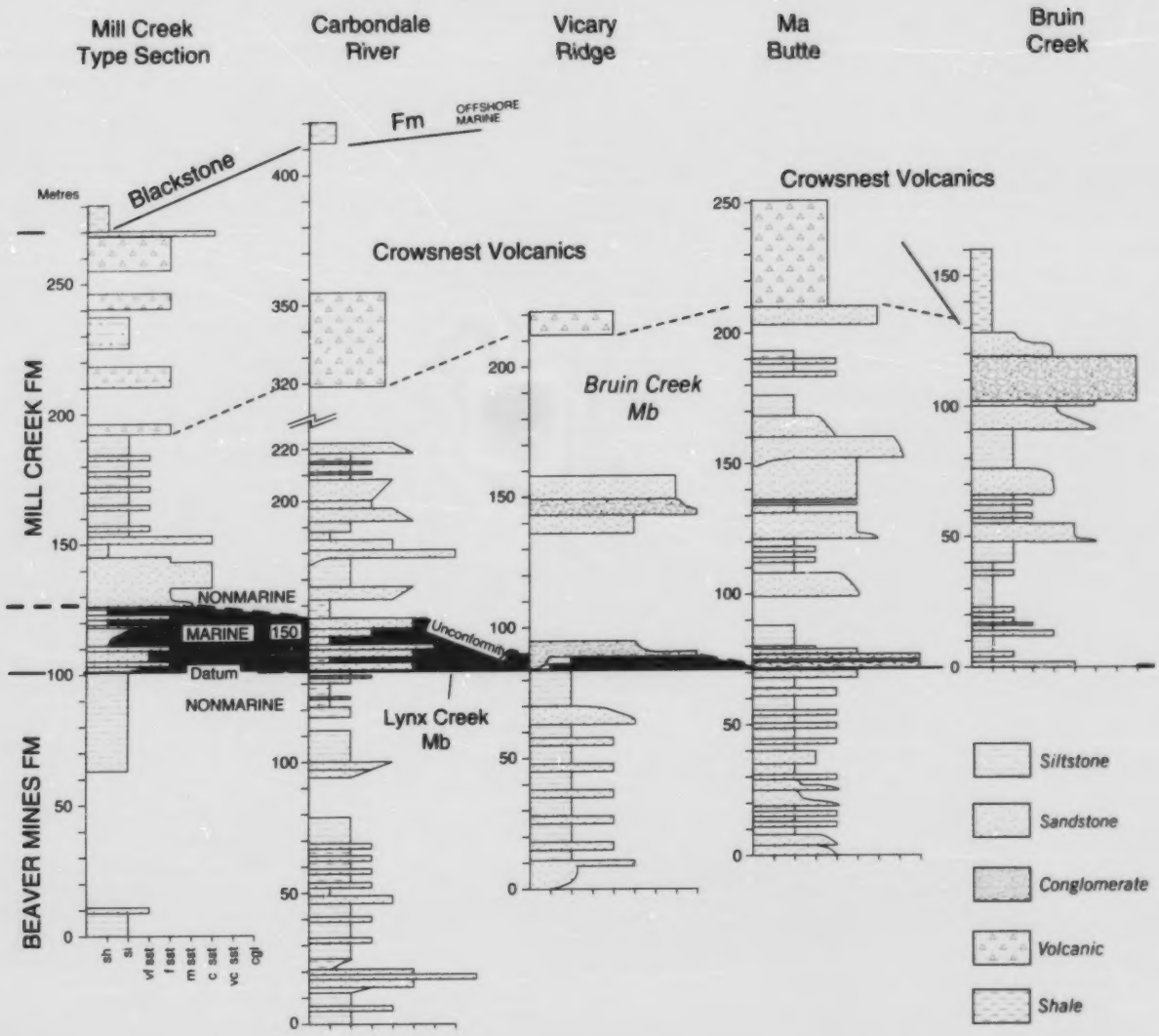


Figure 5. *Regional correlation chart for sections in southwestern Alberta.*

this interval; their presence suggests brackish-water conditions.

Samples from the middle part of the upper Beaver Mines Formation on Carbondale River (C-179825, C-179826) and Mill Creek (C-178401–C178406), about 20 to 100 m below the contact with the Mill Creek Formation, are nearly barren (Fig. 10, in pocket). Small numbers of psilate spores, such as *Cyathidites minor*, *Deltoidospora hallii* and *Laevigatosporites ovatus* dominate this interval. Other spores are corroded, broken and difficult to identify. Prolonged exposure and oxidation can generate this kind of fossil assemblage.

The top 20 m of the Beaver Mines Formation on Carbondale River and at Mill Creek marks a return to conditions favourable for palynomorph preservation. Assemblages are similar to the overlying Lynx Creek Member of the Mill Creek Formation (Fig. 7). Spores include *Pilosisporites trichopapillosus*, *P. brevipapillosus*, *Lophotriletes babsae*, *Triporoletes reticulatus*, *T. radiatus*, *Ischyosporites punctatus*, *Aequitriradites verrucosus*, *A. spinulosus*, *Januasporites spiniferus* and *Couperisporites complexus*. Angiosperm taxa are abundant, and include *Clavatipollenites tenellis*, *C. minutus*, *Racemonocolpites* sp., *Retimonocolpites crassatus*, *R. dividuus*, *R. reticulatus*, *Liliacidites* sp. D and E of Doyle and Robbins, *Liliacidites*

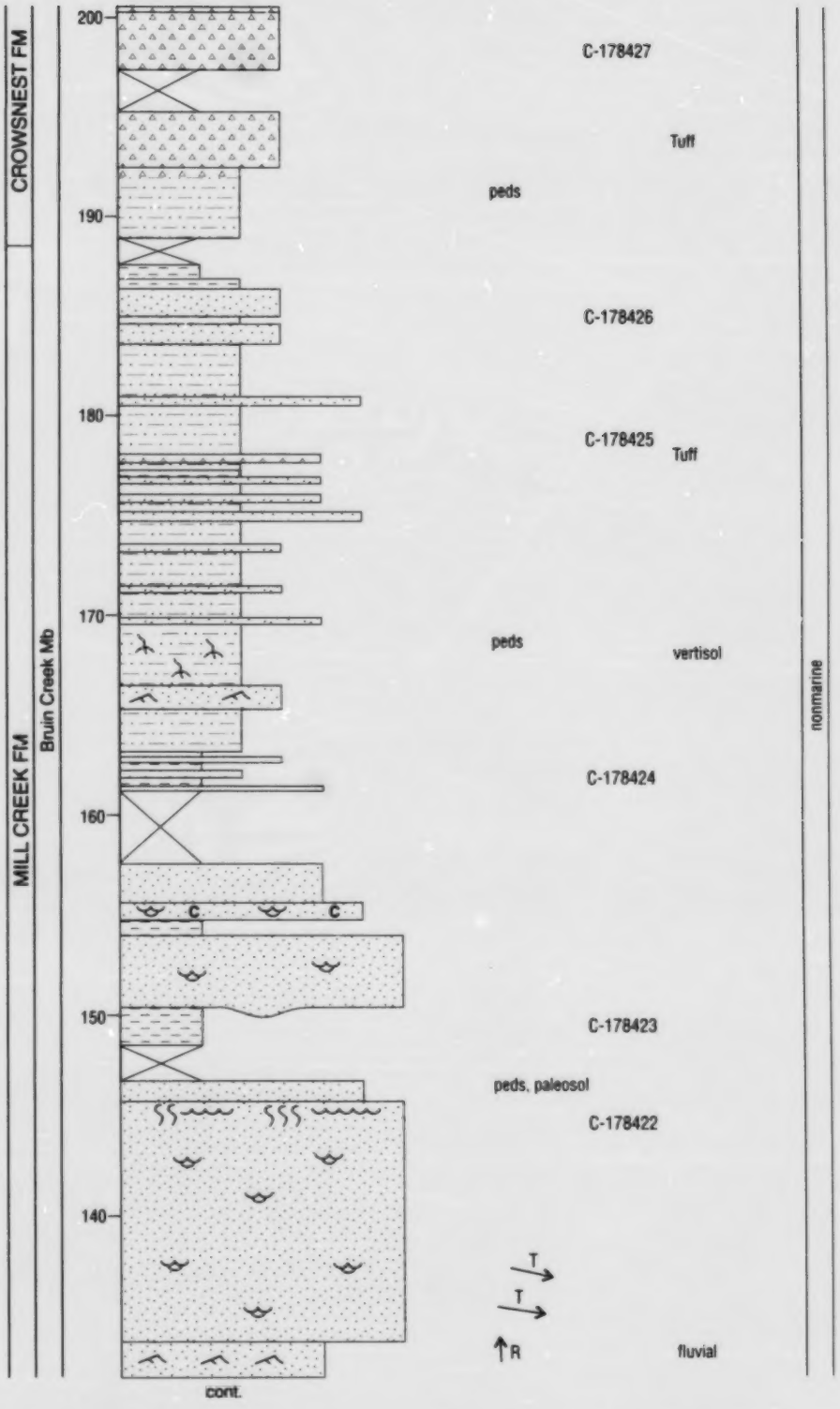


Figure 6. *Measured section of upper Beaver Mines and Mill Creek formations on Mill Creek (MC1). Section contains a reference section for the Lynx Creek Member (for legend, see Appendix 2).*

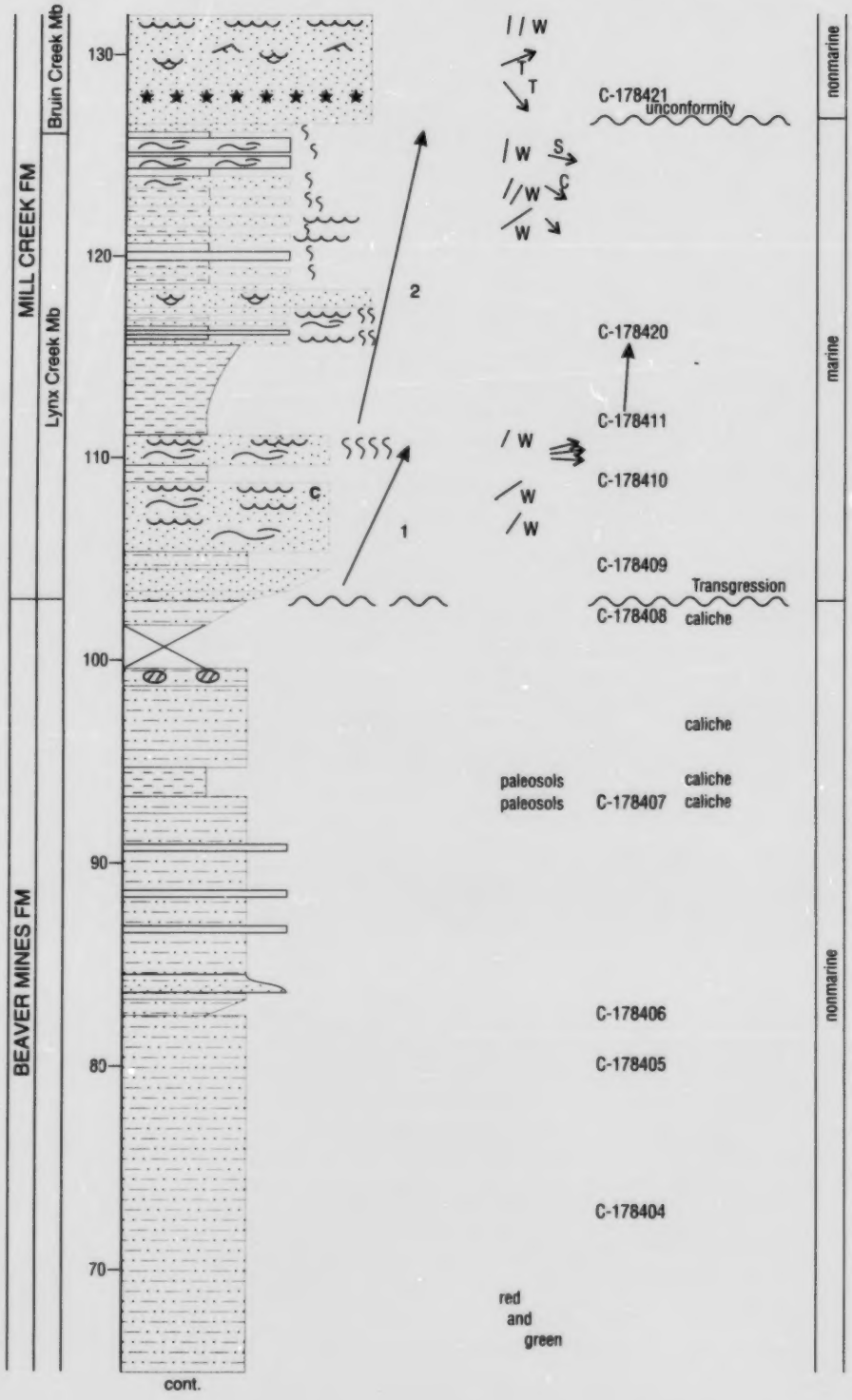


Figure 6. *Measured section continued.*

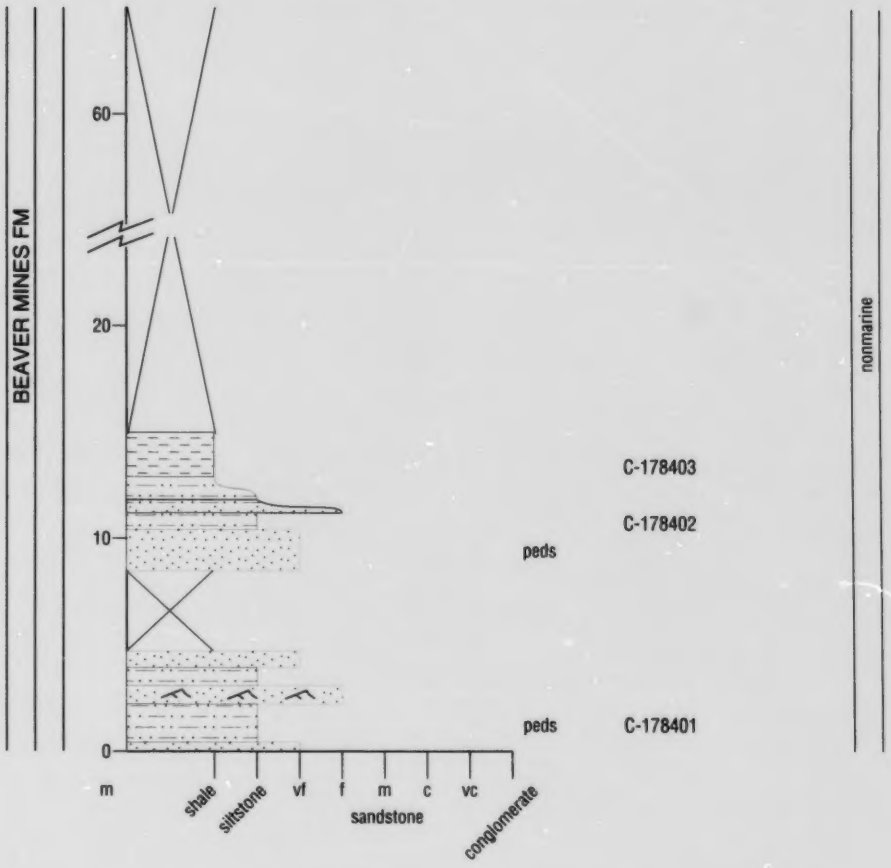


Figure 6. *Measured section continued.*

sp., *Striatopollis* sp., *Cupuliferoidaepollenites parvulus, Foveotricolpites concinnus, Retitrescolpites maximus, R. virgeus, R. vermimurus, Rousea georgensis, R. prosimilis, Tricolpites fragosus, T. micromunus, T. minutus, T. parvus, T. sagax,* and *Ajatipollis* sp. A of Doyle and Robbins. Bryophyte spores of *Couperisporites, Aequitriradites* and *Januasporites* indicate locally wet conditions. Algal species *Schizophacus* sp., *Tetranguladinium conspicuum, Pediastrum* sp. and *Hurlandsia* sp. cf. *H. rugarum* indicate nonmarine conditions or, more likely, slightly brackish-water conditions on Mill Creek. *Microcarpolithes* sp. (form genus) is common in a sample from the top of the Beaver Mines Formation (J.H. Wall, pers. comm., 1990).

The general composition of the palynomorph suites found in the samples analysed from the lowest part of the upper Beaver Mines Formation on the Carbondale River is very similar to the primitive tricolpate suites reported by Singh (1971) for the upper part of the Spirit River Formation (the Loon River Formation of Singh) and the basal part of the Harmon Member of the Peace River Formation in northwestern Alberta. Our results suggest an Early Albian age for the upper Beaver Mines Formation.

Angiosperms from the top of the Beaver Mines Formation, and above the soil beds, are thought to be late Middle Albian in age. These correspond with assemblages from the top of the Harmon and Cadotte members of the Peace River Formation (Singh, 1971) and from zone IIb_2 of the Atlantic Coastal Plain (Doyle and Robbins 1977). Thus, by using assemblages and correlations proposed by Singh (1971) and Doyle and Robbins (1977), our samples of the upper Beaver Mines Formation indicate Early and Middle Albian nonmarine and brackish-water deposits. A prolonged episode of nondeposition and soil development separates the Early Albian from the Middle Albian deposits of the Beaver Mines Formation.

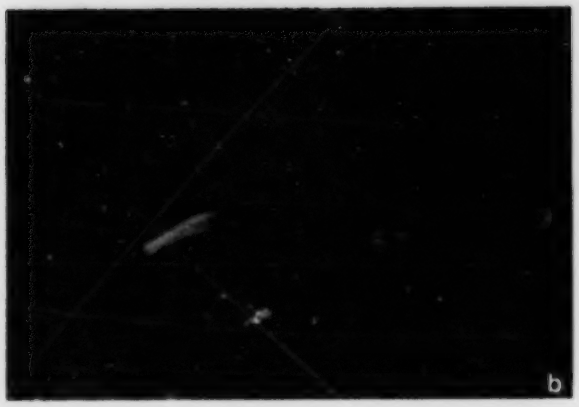


Figure 7. *a) Outcrop of Beaver Mines Formation overlain by the Bruin Creek Member of the Mill Creek Formation. Strata are all nonmarine. Location is on Ma Butte (MC 13).* ***b)*** *Caliche nodules in the upper Beaver Mines Formation. Location is on Mill Creek (MC1).* ***c)*** *Top of Beaver Mines Formation overlain by a few decimetres of the Lynx Creek Member of the Mill Creek Formation. Location is at Vicary Ridge (MC 12).*

Interpretation

The sediments of the upper Beaver Mines Formation represent deposition in an alluvial plain setting with a shallow north- or northeast-dipping slope characterized by sandy and muddy point-bar and overbank deposits. Oxidized fossils, in situ vertical roots, pedogenic slickensides and peds, indicating abundant soil horizons, suggest periods of time between episodes of sedimentation. Detailed interpretations of the paleosols are in McCarthy et al. (1997a,b; 1998). The presence of dinoflagellate cysts indicates periodic and infrequent flooding from brackish-water incursions into southwestern Alberta during this time.

Mill Creek Formation

Lynx Creek Member (new name)

Definition, distribution, and description

The Lynx Creek Member was observed outcropping at Mill Creek, Vicary Ridge, and the Carbondale River (Fig. 5, 8, 9, 11, 12). The contact between the Lynx Creek Member and Beaver Mines Formation is sharp. It is represented by a change from greenish, chloritic-rich sandstone and variegated red/maroon and green siltstone and shale of the Beaver Mines Formation to white, quartz-rich sandstone and

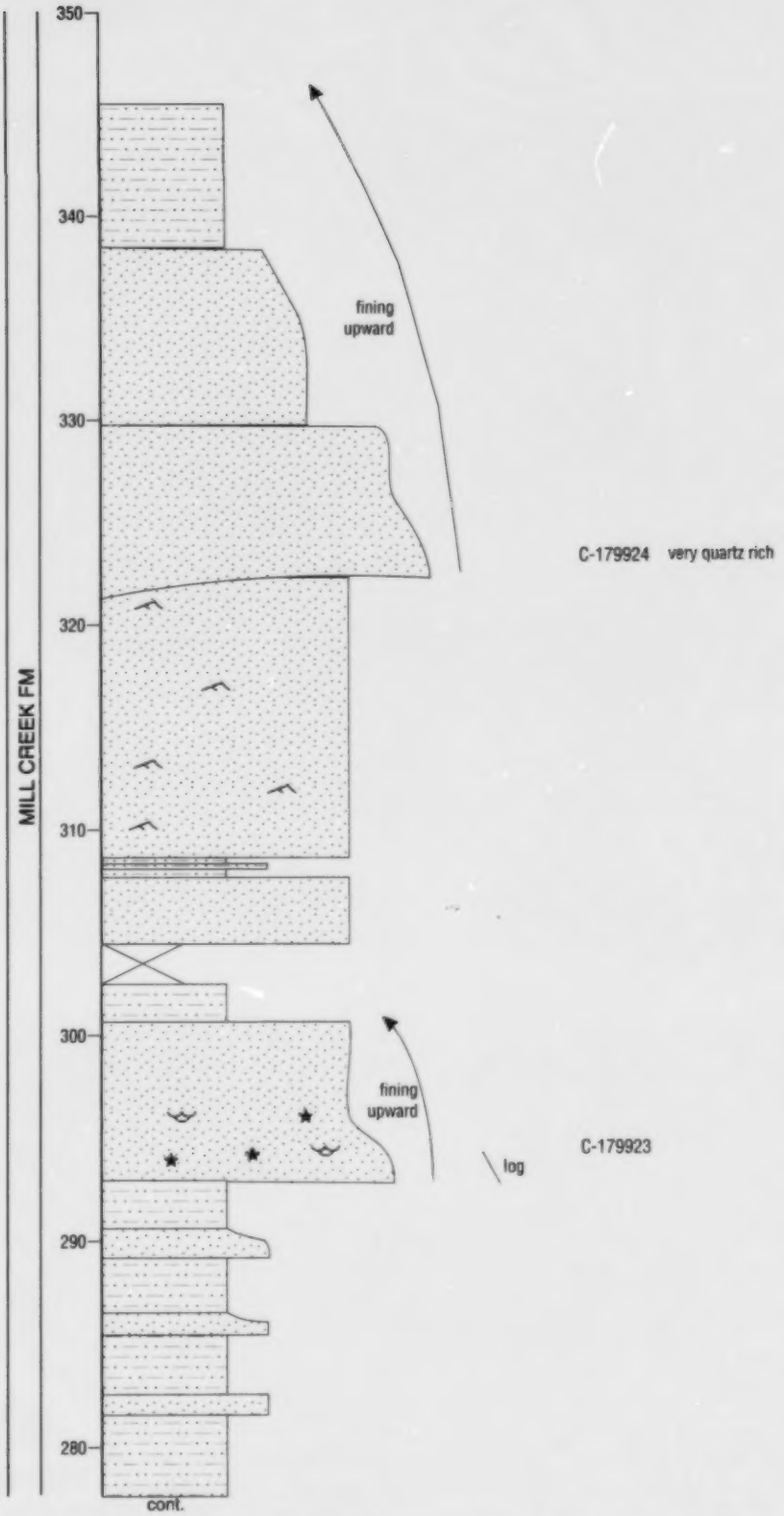


Figure 8. *Measured section of reference section of Bruin Creek Member at Ma Butte (MC 13) (for legend, see Appendix 2).*

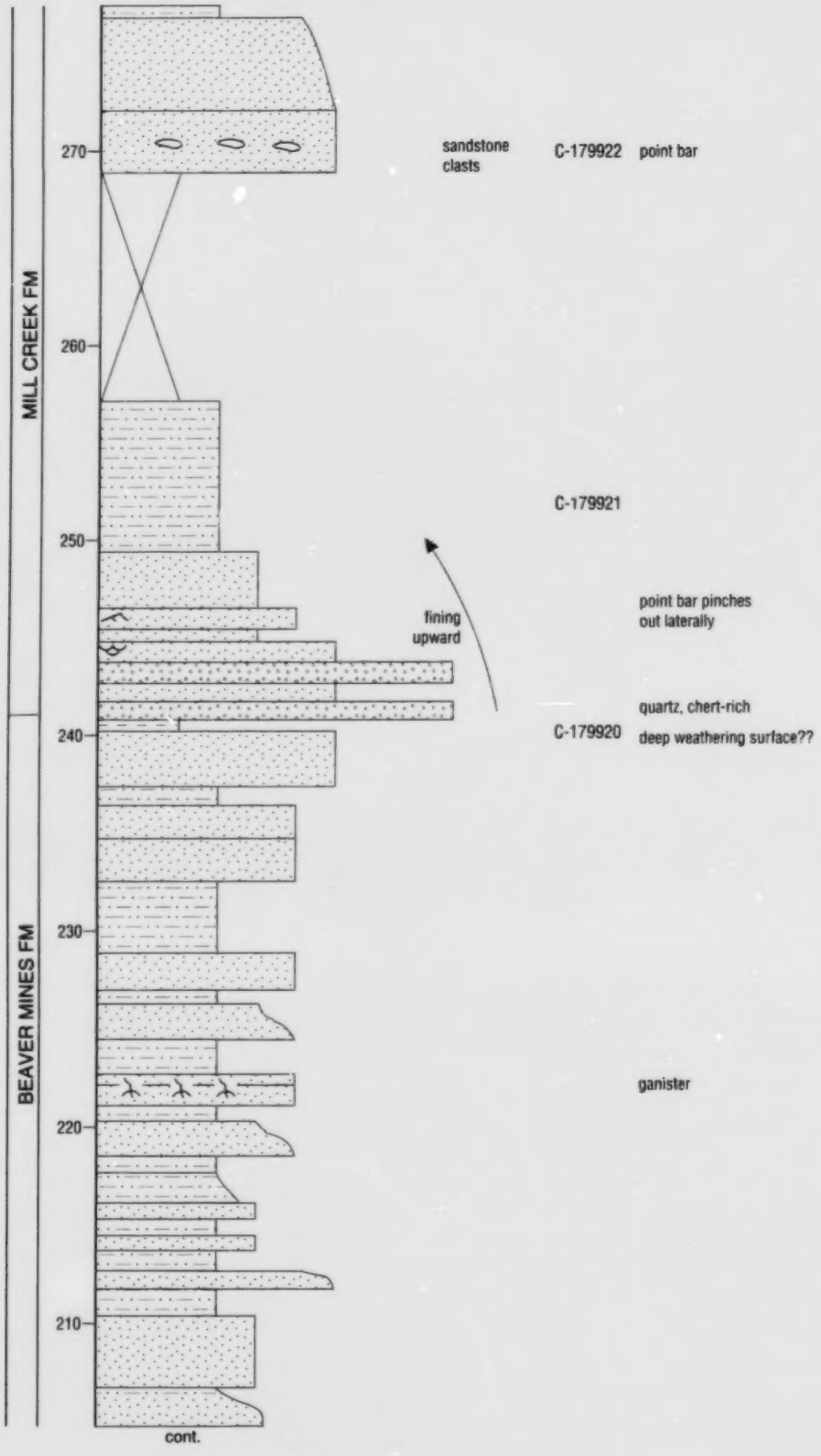
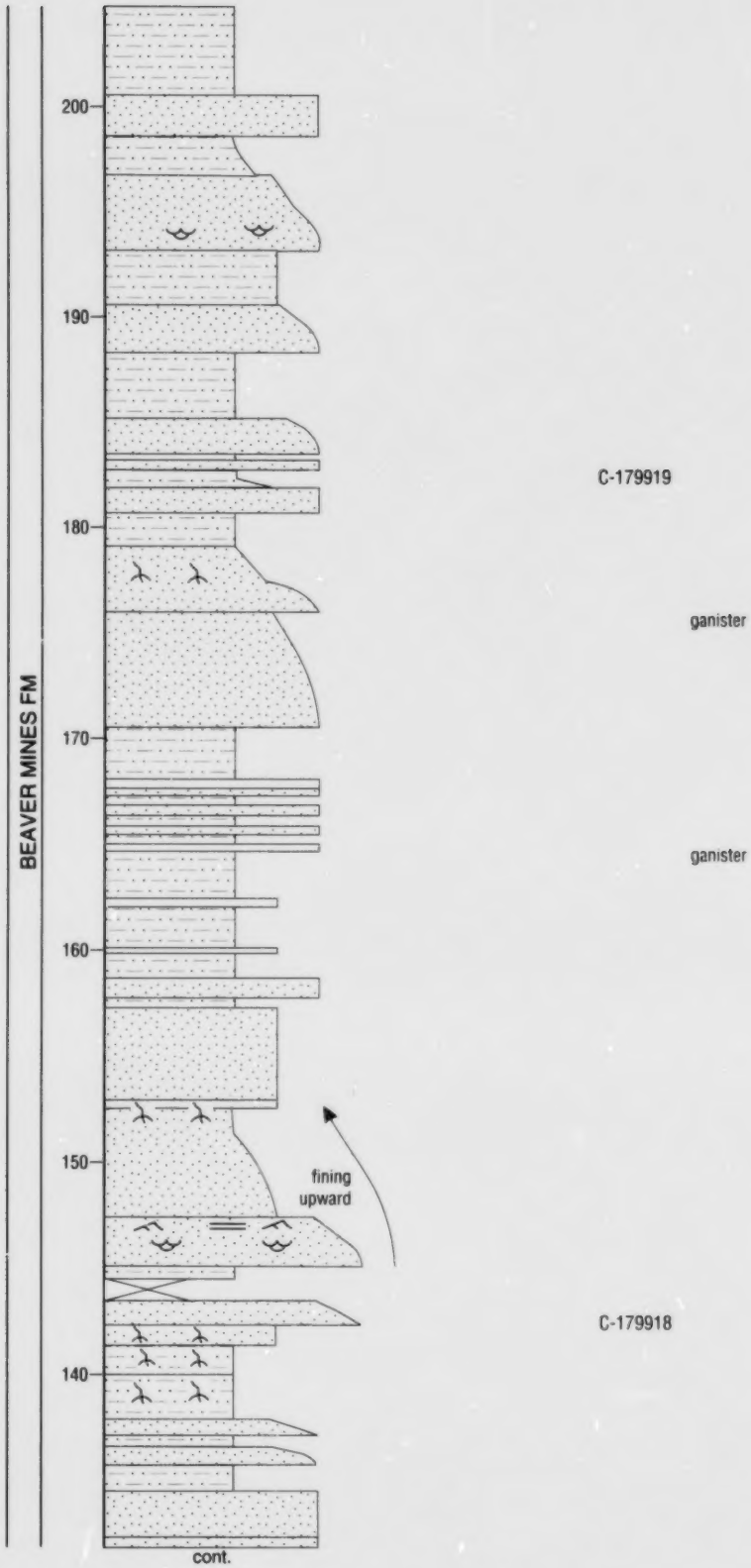


Figure 8. *Measured section continued.*



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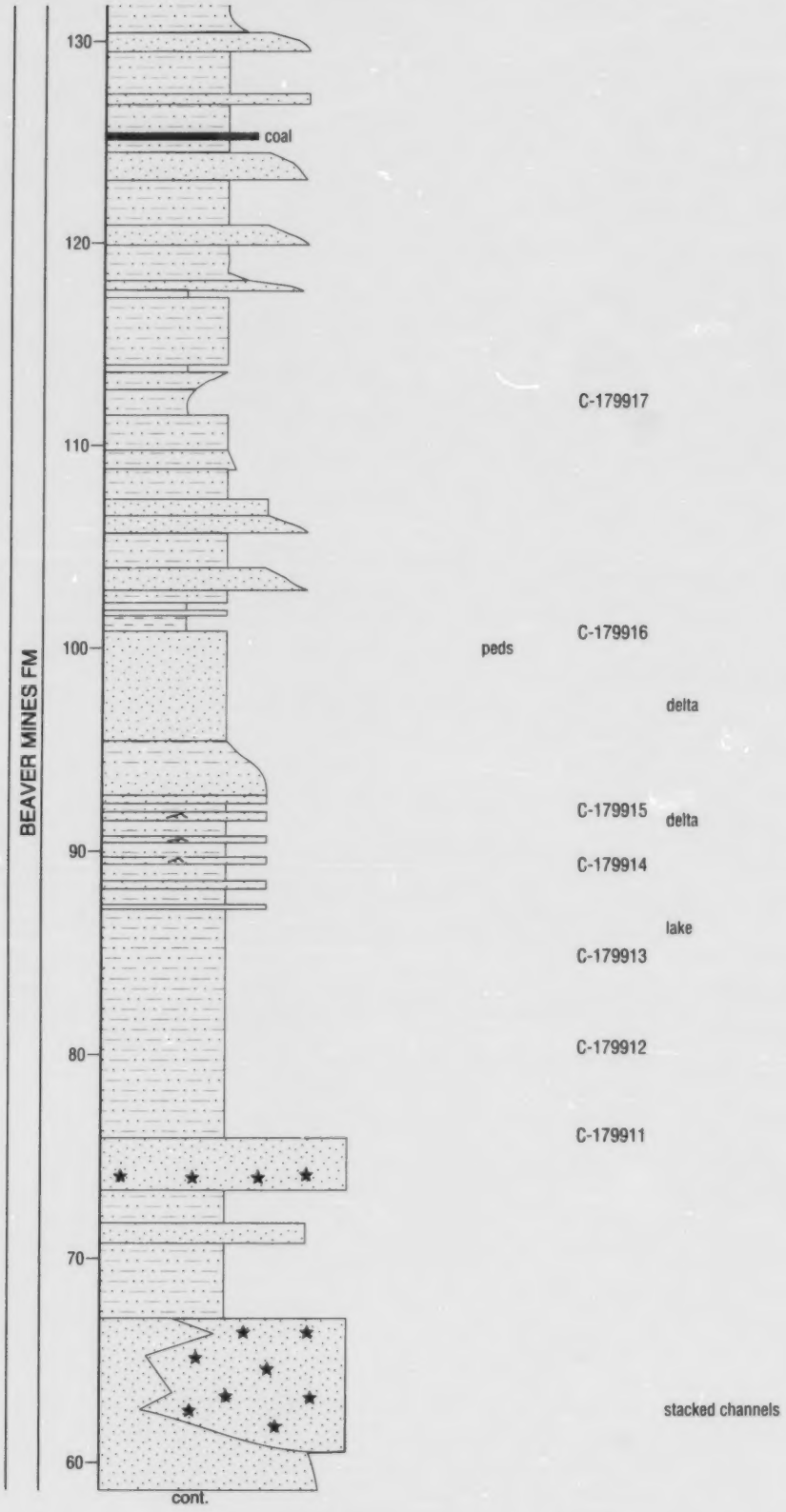

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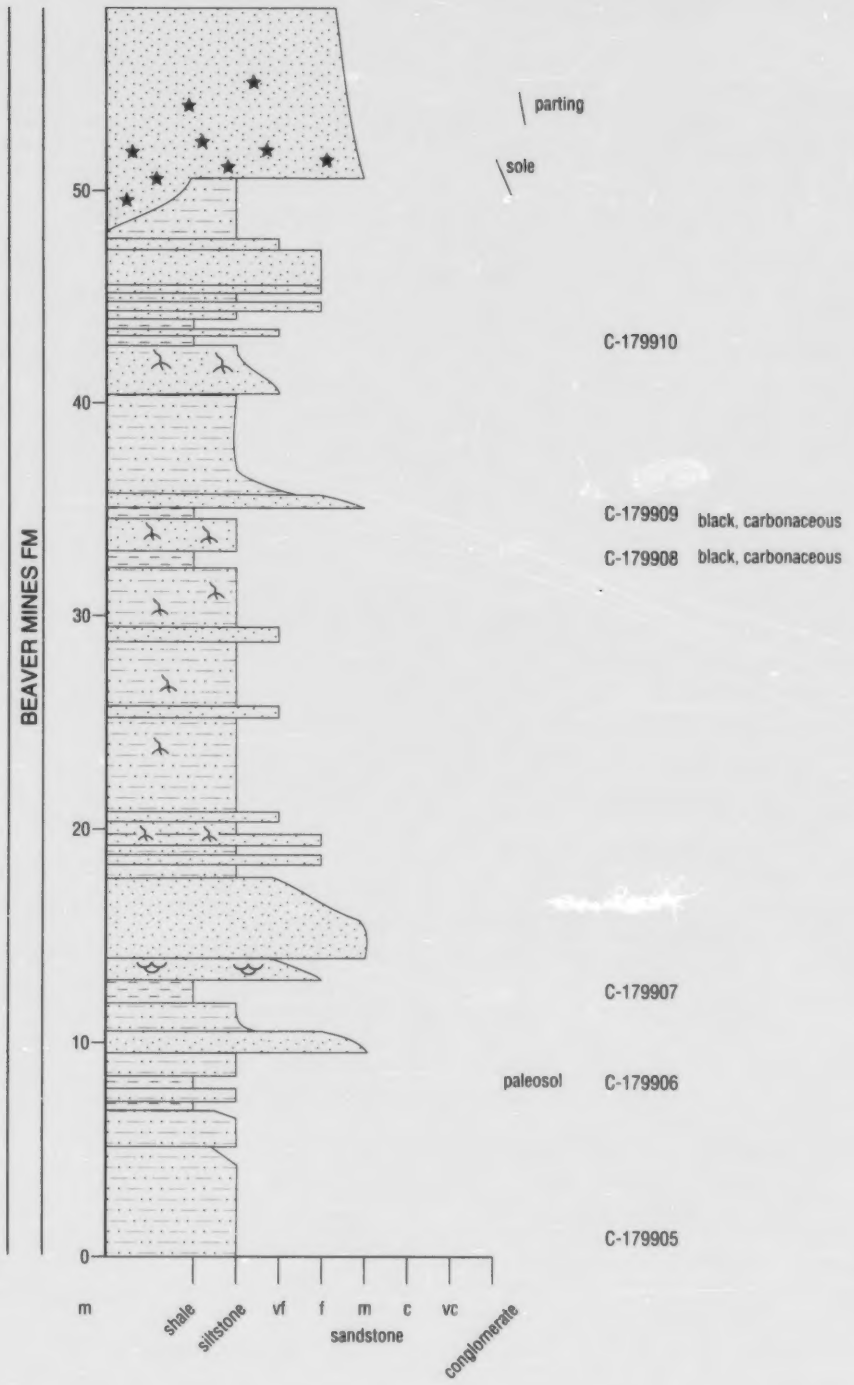


Figure 8. *Measured section continued.*

dark grey to black shale and siltstone of the Lynx Creek Member. A geological map of the region surrounding the type section is in Price (1962).

Interbedded shale, siltstone, and quartzose sandstone of the Lynx Creek Member typically occur in coarsening-upward cycles approximately 10 m thick. Variegated strata are uncommonly found at the top of the member. Flutes,

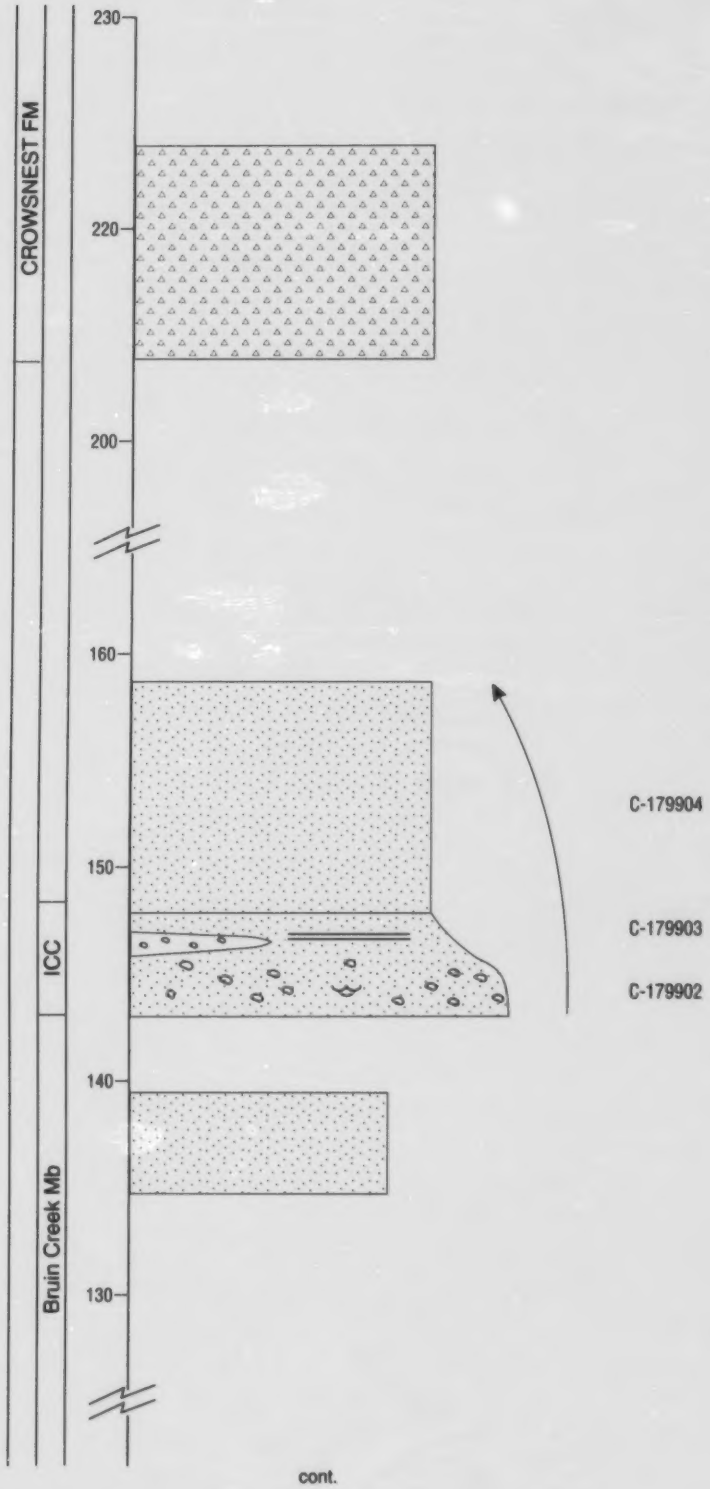


Figure 9. *Measured part (MC 12) of reference section of Lynx Creek Member at Vicary Ridge (ICC - igneous clast conglomerate) (for legend, see Appendix 2).*

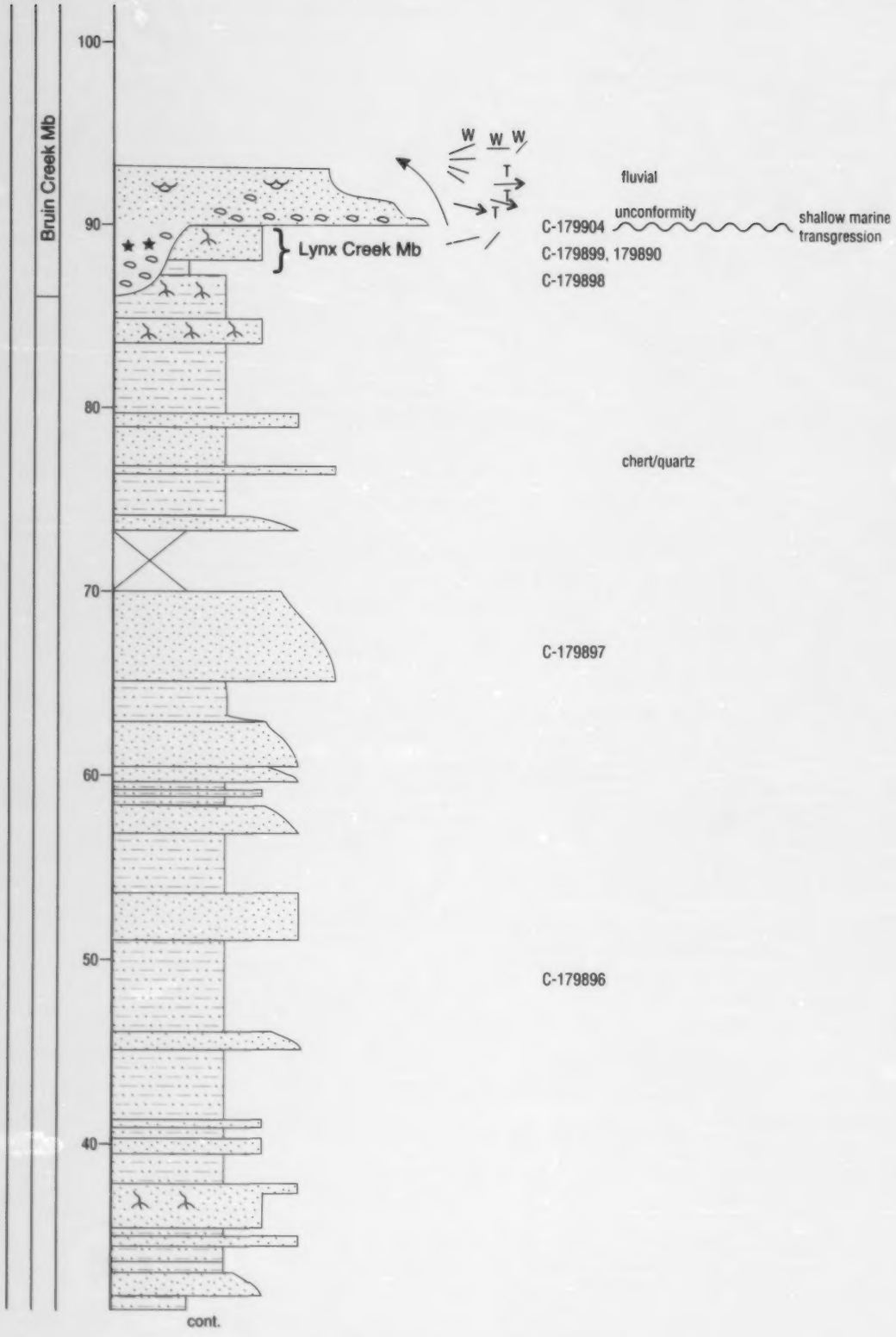


Figure 9. *Measured section continued.*

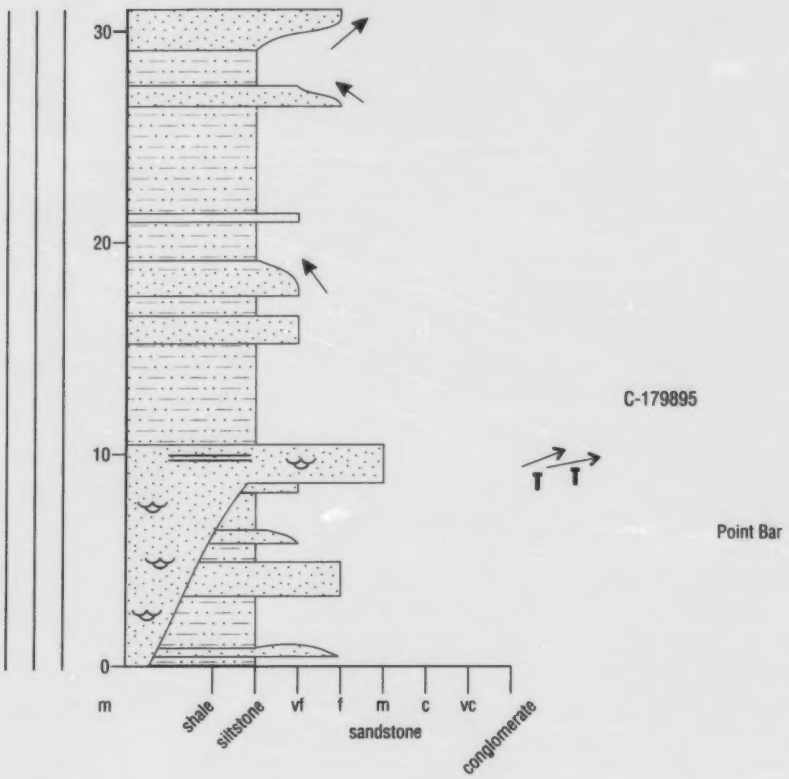


Figure 9. *Measured section continued.*

prod marks, load structures, laminae, trough and hummocky crossbeds, and wave ripples are common in the sandstone; mudstone is generally bioturbated. The Lynx Creek Member is approximately 25 m thick at Mill Creek in the east, but thins and is erosionally truncated to the north and west where it is absent at Ma Butte (Fig. 5).

The Lynx Creek Member contains marine to brackish-water palynomorphs, microfossils, macrofossils, and trace fossils. Sedimentary structures and fossils indicate that Lynx Creek Member strata probably formed in shallow-marine and shoreline environments. The palynomorphs and microfossils suggest that correlative horizons in Western Canada are the upper Hulcross Formation and upper Harmon and Cadotte members of the Peace River Formation of northeastern British Columbia and northwestern Alberta. The Lynx Creek Member may be correlative with strata of the Colony Formation of Saskatchewan and the central Alberta plains.

Lithology and sedimentology

Type section: Carbondale River (MC 6). The type section of the Lynx Creek Member is situated on the Carbondale River upstream of the junction with Lynx Creek (Fig. 1). Access to the outcrop can be obtained by parking in the Alberta Forestry Service Lynx Creek Campground. A detailed description of the type section is given in Figure 9.

The Lynx Creek Member at the type locality (Fig. 11) is 42.3 m thick and consists of three, coarsening-upward cycles (Fig. 5, 7, 11). The lowermost coarsening-upward succession is not as well defined as the upper two. The basal contact is sharp and represented by a bioturbated, very fine-grained, light-coloured sandstone overlain by a mixed, 1.8 m thick bioclastic–siliciclastic bed. The bioclastic component consists of poorly sorted, broken and disarticulated shell debris of *Ostrea*? sp., nuculid bivalve fragments,

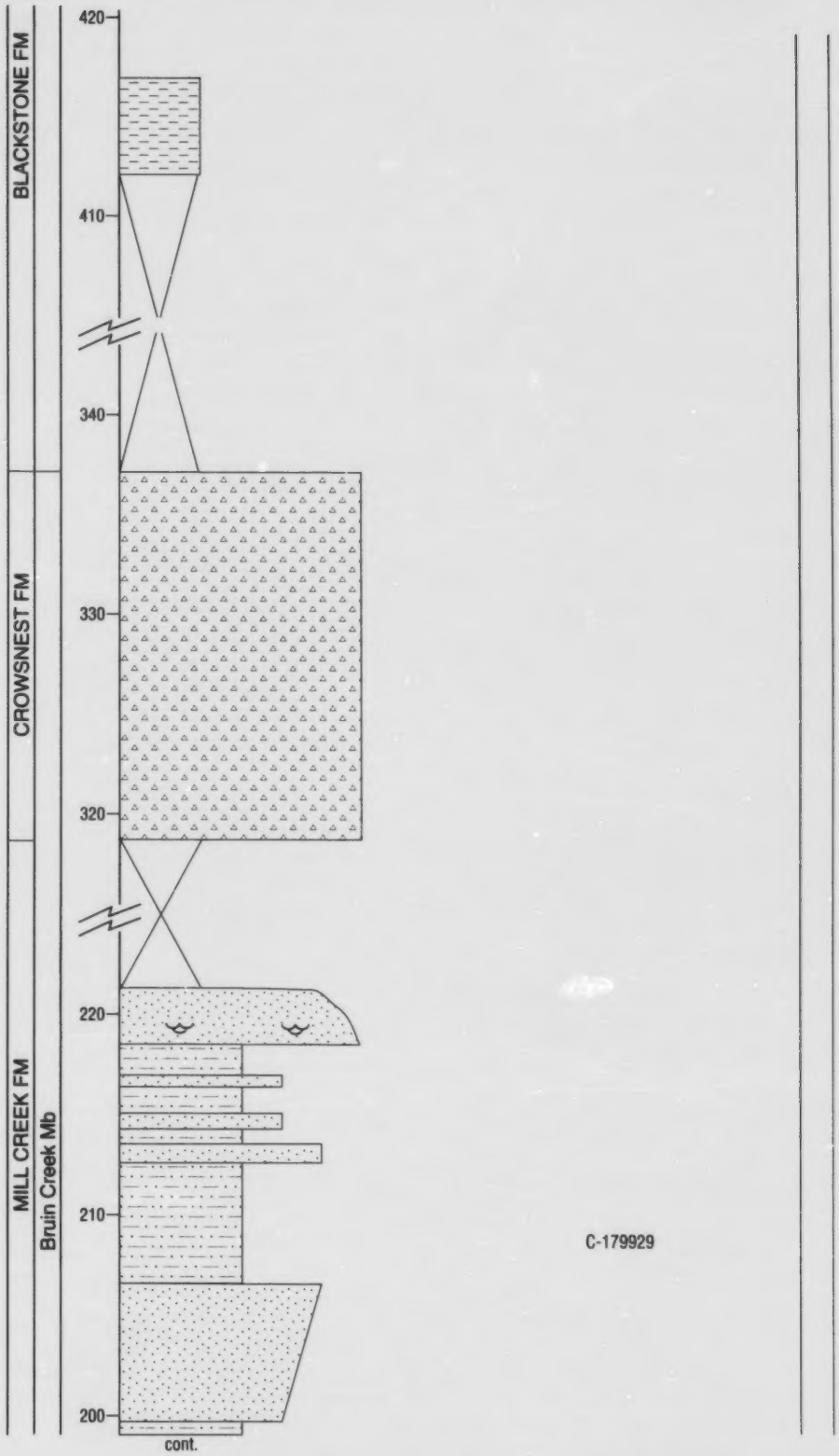


Figure 11. *Measured section of type section of Lynx Creek Member at Vicary Ridge (for legend, see Appendix 2).*

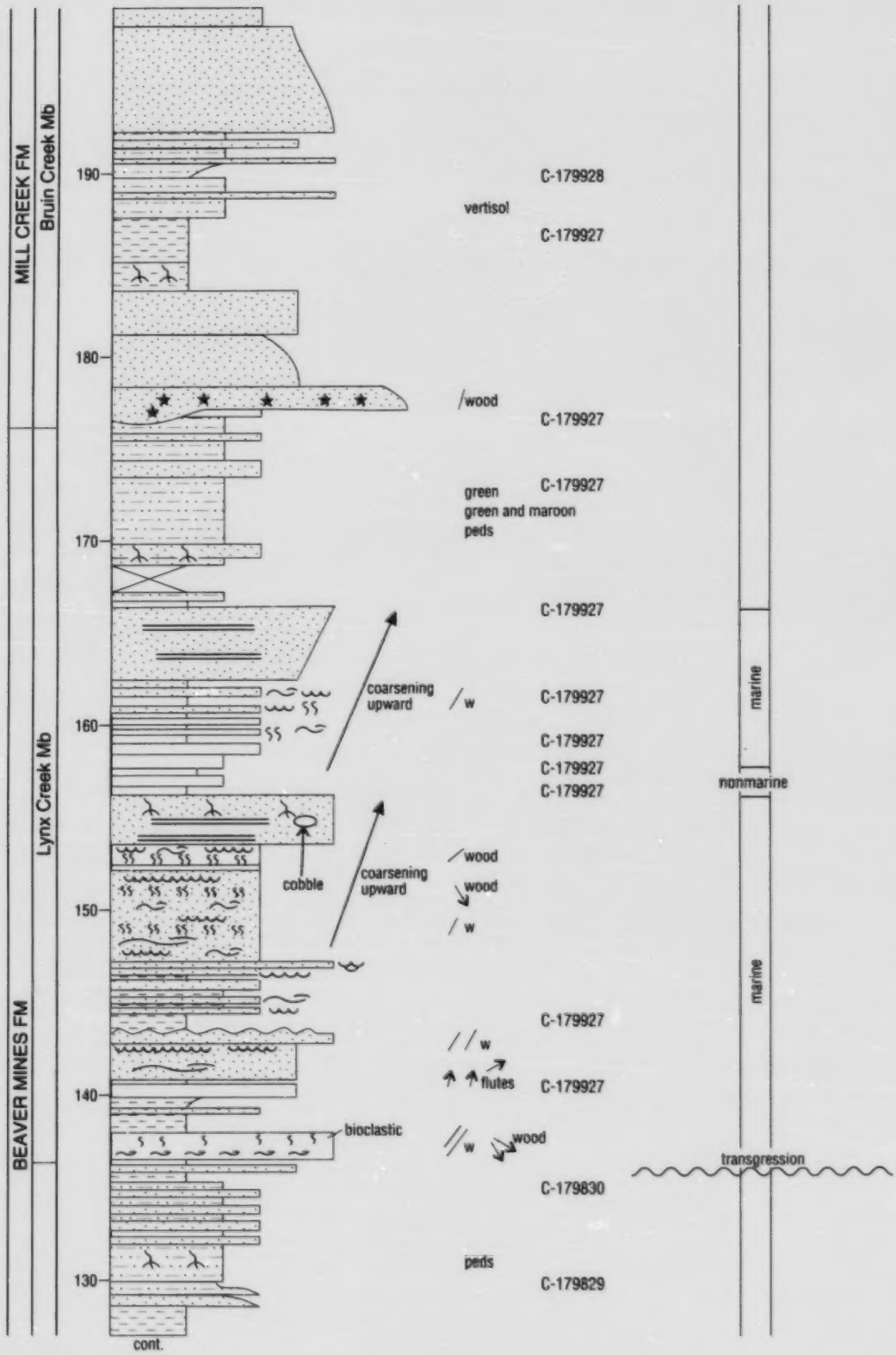


Figure 11. *Measured section continued.*

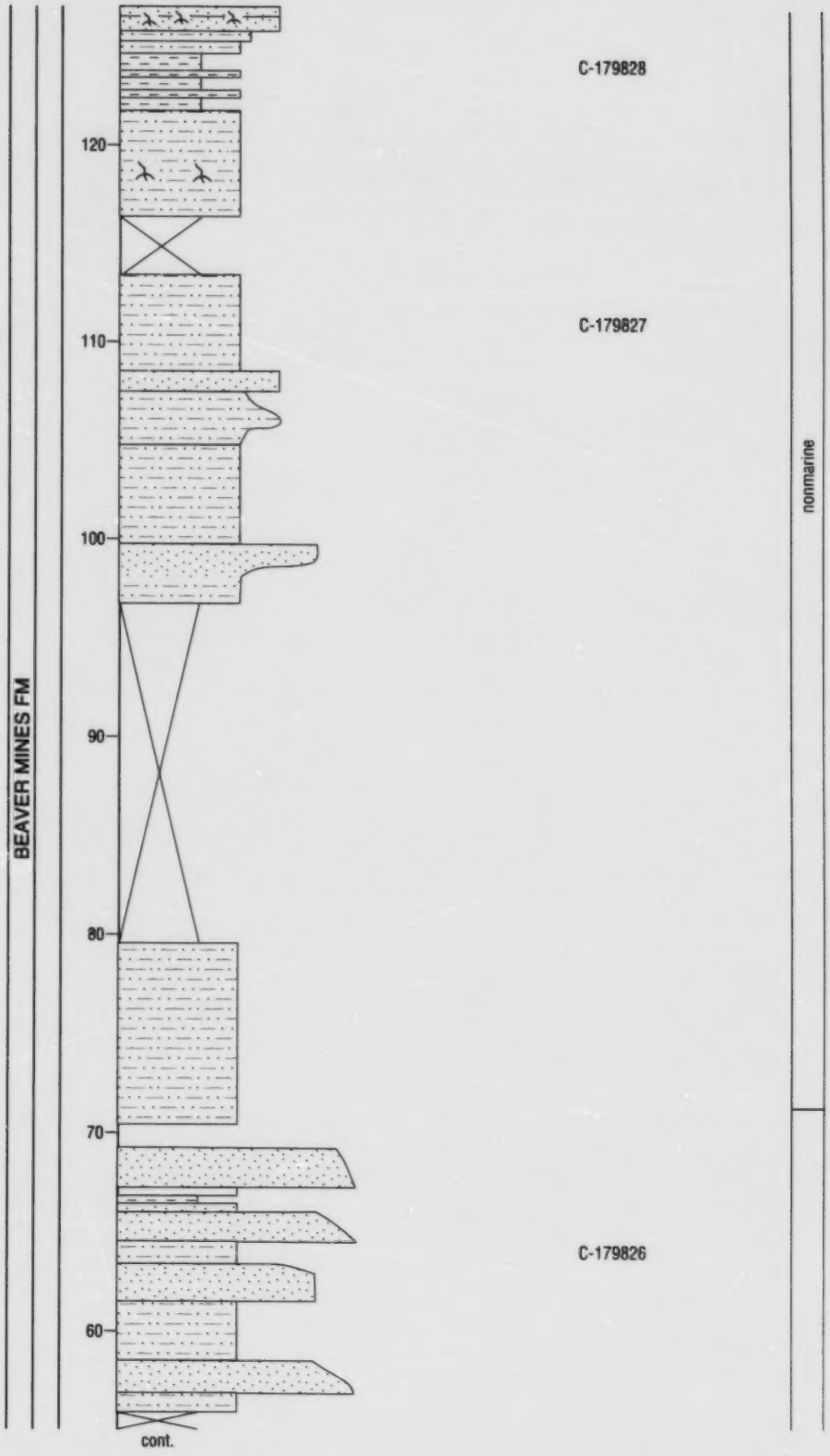


Figure 11. *Measured section continued.*

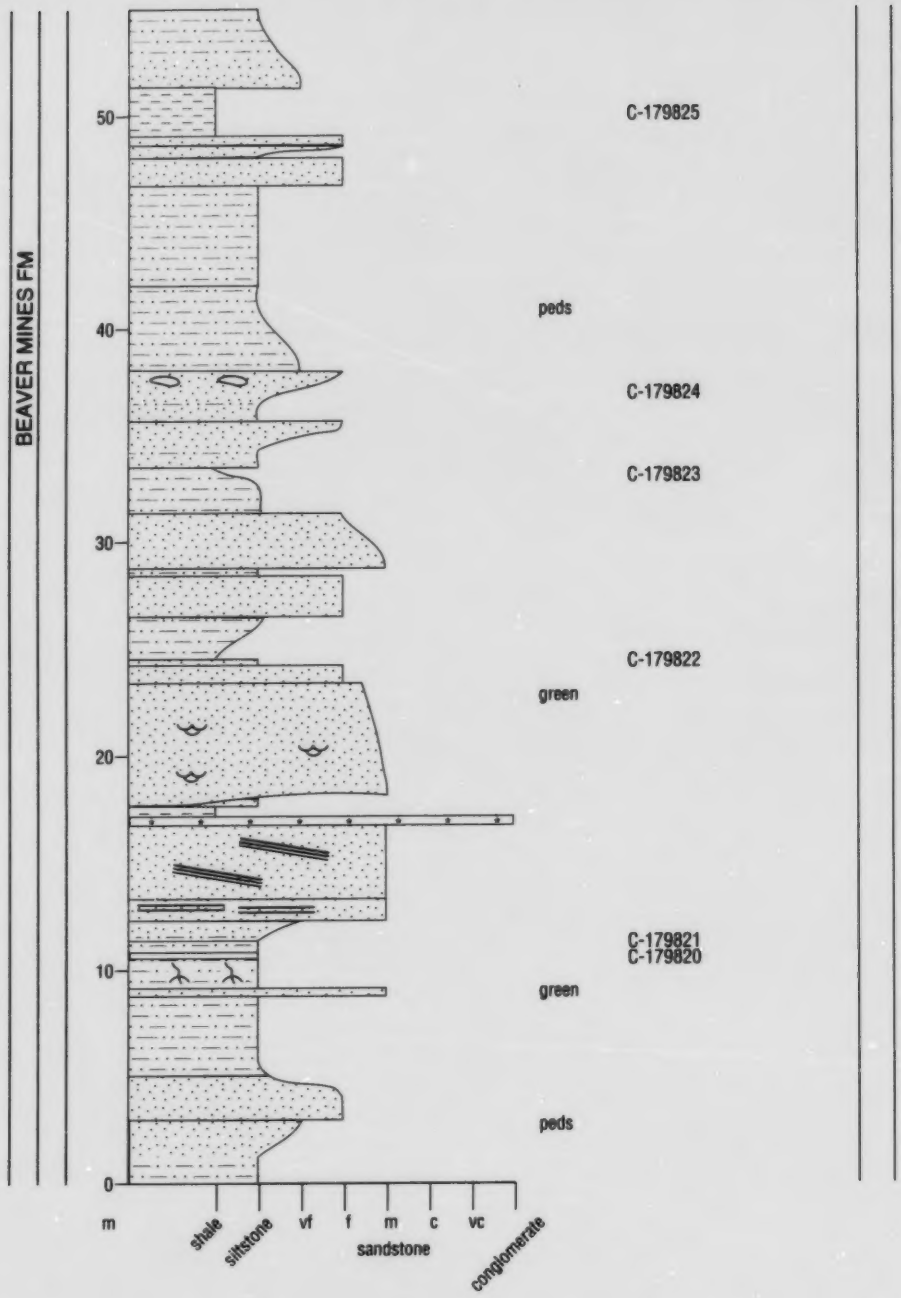
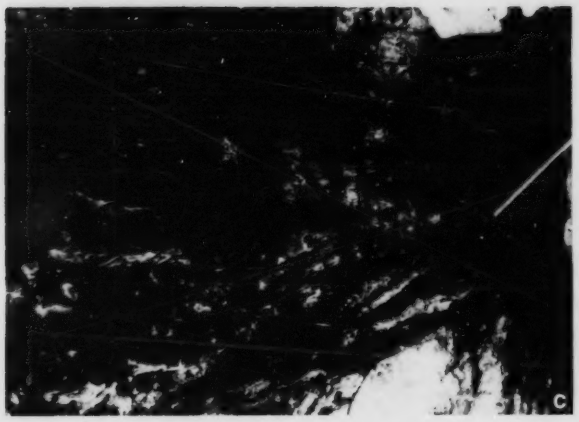


Figure 11. *Measured section continued.*

Figure 12. *Lynx Creek Member.* ***a)*** *Coarsening-upward cycle of Lynx Creek Member on Mill Creek (MC1).* ***b)*** *Top of second coarsening-upward cycle overlain by paleosols, a transgressive surface and then the upper coarsening-upward cycle, which terminates in foreshore sandstone. On Carbondale River (MC6).* ***c)*** *Fluted basal surface in upper cycle on Carbondale River (MC6).* ***d)*** *Coarsening-upward cycle on Carbondale River (MC6).* ***e)*** *and* ***f)****. Hummocky cross-stratified sandstone in Lynx Creek Member on Carbondale River (MC6).* ***g)*** *Angular unconformity of Bruin Creek Member overlying Lynx Creek Member. There are only a few decimetres of Lynx Creek Member preserved at this outcrop. Location is at Vicary Ridge (MC12).*

a

b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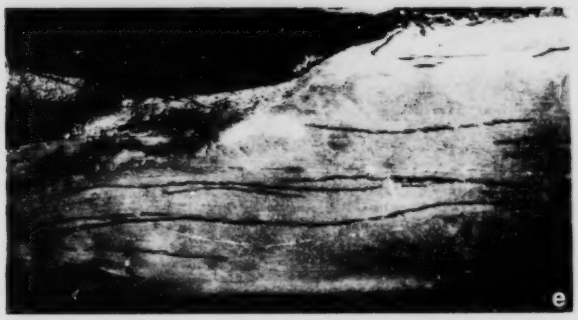
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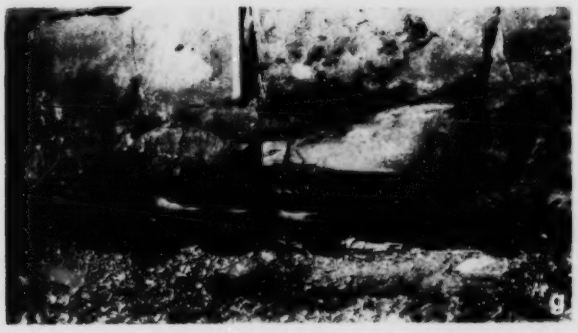
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unidentified bivalve fragments, *Tancredia*? sp., *Melania* sp., and gastropod fragments (J. Haggart, pers. comm., 1990). Bioturbation is moderate and includes *Pelecypodichnus*. Wave-ripple crests at the top of the bed trend northeast, subparallel to the local paleoshoreline (c.f., Leckie and Krystinik, 1989). Oriented wood debris at the base trends northwest and was directed offshore (Fig. 13).

The basal bed is overlain by a 5.5 m thick, coarsening-upward succession. The base of the succession consists of a 1 m thick shale containing dinoflagellates and tintinnids (C-179852, C-179853). Sandstone beds are very fine- to fine-grained and increase in number and thickness upward. The sandstone beds are hummocky cross-stratified and wave-ripple laminated. The top of the cycle is characterized by a 60 cm thick, medium-grained sandstone bed, containing coarse-grained wave ripples with a wavelength of 20 cm and an amplitude of 2.2 cm. The wave ripple crests are well rounded and have an anastomosing crestal pattern. In places, there is also a box-like interference pattern. The ripple crests trend 23–203° (Fig. 13).

Five metres from the base of the Lynx Creek Member is a 1.9 m thick sandstone bed that has spectacular solemarks at its base (Fig. 12C). The relief on the base of the bed is up to 30 cm and sole marks include flutes up to 2 m long and 1 m wide. The largest flute flares out toward 55°; other sole marks trend 28–208° and 26–206° (Fig. 13). Within the fluted surface are prod marks and brush marks, several of which crosscut one another. The brush marks range from 1 mm to 10 cm wide. The sandstone is fine grained and hummocky cross-stratified. The upper 30 cm contains possible wave-ripple laminae.

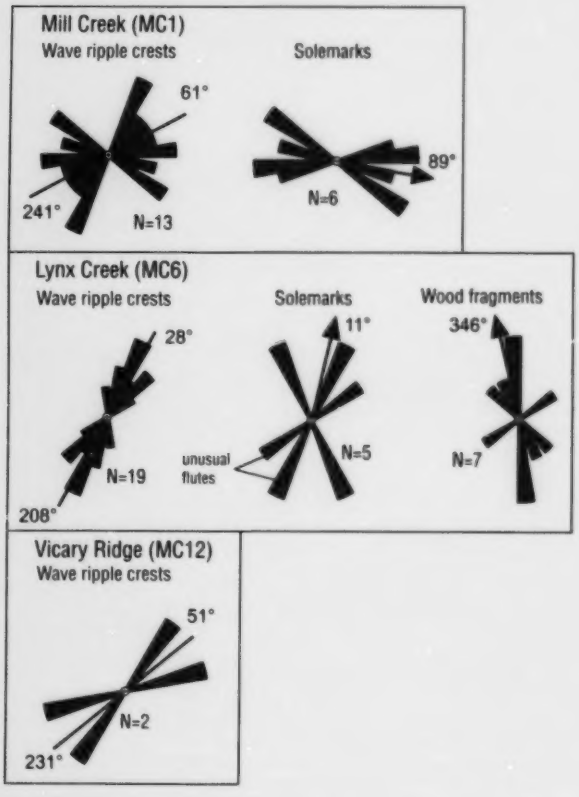


Figure 13. *Paleocurrents from marine Lynx Creek Member.*

The second coarsening-upward succession is 12.9 m thick and consists of 3.4 m of interbedded sandstone and shale. The sandstone contains hummocky cross-stratification and wave-ripple laminae. Bioturbation is light to moderate, and consists of *Thallasinoides* and unidentified forms. The upper 9.3 m is a very fine-grained sandstone that coarsens upward to medium grained. The lower 6.5 m is an amalgamated HCS sandstone. Wave-ripple crests trend northeast–southwest (Fig. 13). The upper 2.6 m consist of parallel-laminated, medium-grained sandstone with individual 10 to 15 cm thick bed sets exhibiting low-angle divergences. One metre from the top of the sandstone is an isolated 9 x 5 cm chert cobble. The upper 15 cm of the sandstone are very carbonaceous and contains in situ vertical roots, some of which appear to have horizontal rhyzomes spreading from a vertical root. The exhumed upper surface of the sandstone has irregular relief up to 30 cm. The top of the second cycle consists of 1 m of rooted and pedogenically altered shale and siltstone (Fig. 11)

The third coarsening-upward cycle is 9 m thick and generally similar to the second cycle. Wave-ripple crests from the tops of hummocky beds trend north-northeast (Fig. 13).

Conformably above the third cycle there lie an additional 11.5 m of Lynx Creek Member consisting of interbedded sandstone, siltstone and shale. Siltstone and shale beds vary in colour from green to grey to maroon. In situ vertical roots and pedogenic slickensides are common. Isolated sandstone bodies pinch out laterally.

The contact between the Lynx Creek and Bruin Creek members is a prominent erosion surface. Forty-four metres of the Bruin Creek Member are exposed along the Carbondale River; the rest of the section is covered. Exposures of the Crowsnest Formation outcrop approximately 144 m above the base of the Bruin Creek Member. The contact between the Crowsnest Formation and Bruin Creek Member is obscured.

Reference section: Mill Creek (MC 1). At Mill Creek (MC1, Fig. 1), the Lynx Creek Member is 22.9 m thick and consists of two coarsening-upward cycles capped with a thick bedded, cherty sandstone of the Bruin Creek Member (Fig. 5, 6). The lower contact is sharp and marked by a change in colour from the variegated olive greens and reds of

the Beaver Mines Formation to the lighter-coloured quartzose sandstone and dark grey to black shale of the Lynx Creek Member. The peds, pedogenic slickensides, and caliche nodules found in the Beaver Mines Formation do not occur in the Lynx Creek Member at Mill Creek.

The lowermost coarsening-upward cycle is 7.6 m thick and consists of interbedded sandstone and shale. The sandstone is predominantly fine grained with lesser amounts of very fine- and medium-grained material. Sandstone beds are 0.9 to 4.3 m thick and are wave-ripple laminated, parallel-laminated and hummocky cross-stratified (Fig. 14). Wave ripple crests have an average trend of 35–215°. At the base of one sandstone bed is a spectacular set of solemarks (109.7 m, Fig. 6, 12C), including prods, brushmarks and tools. The average trend of the solemarks is 82° with the prods indicating flow toward the east (Fig. 13).

The second coarsening-upward cycle, which is 15.3 m thick, consists of 4.4 m of black, platy, fissile shale and silty shale overlain by 10.9 m of interbedded sandstone and shale. Sandstone beds are 10 to 70 cm thick, very fine grained, and contain hummocky cross-stratification and wave-ripple laminae. At 118 m (Fig. 5, 6), there is a 70 cm thick, trough-crossbedded, medium-grained sandstone. To the eroded top of the member at about 126 m, the remaining sandstone beds are sharp based, and the tops of the beds are intensely bioturbated. The sandstone beds in this interval generally increase in thickness upward to about 30 cm. The wave ripples have an 8 cm wavelength and an amplitude of 0.5 cm; wave-ripple crests have a trend of 43–223° (Fig. 13); solemarks at the bases of hummocky beds indicate flow toward the east (Fig. 13).

Reference section: Vicary Ridge (MC12). At Vicary Ridge, only 3 m of the Lynx Creek Member are preserved (Fig. 1, 5, 9). Here, the member consists of 30 cm of black silty shale overlying rooted siltstone of the upper Beaver Mines Formation. The shale is overlain by up to 1.8 m of very fine-grained sandstone containing wave-ripple laminae and vaguely defined hummocky cross-stratification. Wave-ripple crests trend northeast–southwest (Fig. 13). There is minor bioturbation (burrows unidentified) at the base of the sandstone. Elsewhere on Vicary Ridge, this bed was eroded to 0.2 m before the overlying cherty sandstone and conglomerate of the Bruin Creek Member were deposited. Overall, the Lynx Creek Member thins laterally toward the top of the Ridge and is truncated by channelized sandstone deposits of the Bruin Creek Member.

A short distance west, the Lynx Creek Member is not preserved. At Ma Butte, it has been been eroded by the unconformity at the base of the Bruin Creek Member. Here, Bruin Creek strata lie directly upon the Beaver Mines Formation.

Age and paleontology

Lynx Creek Member strata are characterized by their marine palynomorphs and relatively diverse fungal spores. Marine taxa common in the Lynx Creek Member on Mill Creek (Fig. 10) include *Balmula tripenta, Nyktericysta davisii, Pseudoceratium interiorense, Laciniadinium arcticum, Cometodinium whitei, Apteodinium granulatum, Oligosphaeridium complex, Fromea* sp. cf. *F. fragilis, Tasmanites* sp. and *Lecaniella foveata*. Nonmarine or brackish-water species *Schizophacus* sp., *Tetranguladinium conspicuum, Pediastrum* sp., *Scenedesmus* sp., *Tetraedon* sp., *Schizosporis* sp., *Tetraporina horologia* and *Hurlandsia* sp. cf. *H. rugarum*, indicate mixing of fresh and salt water.

Spore and pollen taxa in the Lynx Creek Member are very diverse (Fig. 10). Biostratigraphically significant spores include *Appendicisporites cristatus, A. matesovae, A. spinosus, A. tricostatus, Cicatricosisporites patapscoensis, Distaltriangulisporites mutabilis, Interulobites intraverrucatus, Scopusporis spackmanii, Foveogleicheniidites confossus* and *Ischyosporites disjunctus*. One specimen of *Camarozonosporites ambigens* is present. Angiosperms are dominantly tricolpate forms (some taxa have rudamentary oroid apertures). New entrance level angiosperm taxa include *Asteropollis asteroides, A. trichotomosulcatus, Clavatipollenites hughesi, Liliacidites doylei, L. inaequalis, Retimonocolpites textus, Rousea brenneri, R. miculipollis, Tricolpites crassimurus, T. vulgaris, Penetetrapites mollis* and *Quadricolpites reticulatus*.

Microfossils recovered and identified from the Lynx Creek Member at Mill Creek include *Reophax*, fish teeth, and bone fragments, charophyta (genus indeterminate), *Ammobaculites* (?) sp., *Haplophragmoides* sp., *Gaudryina* (?) sp., and the tintinnid *Dicloepella borealis*. At Carbondale River, the microfossil assemblage is limited, and includes only Ostracoda (genus indeterminate) and *Dicloeopella borealis* (J.H. Wall, pers. comm., 1989)

Recycled Paleozoic spores, indicative of elevated and eroding Paleozoic terrains, are relatively common in some samples. In addition, Early Cretaceous recycling is suggested in assemblages where *Contignisporites glebulentus, Cicatricosisporites crassistriatus, Tauro-cusporites segmentatus, Concavissimisporites parkinii* and *Microreticulatisporites uniformis* occur together.

The tintinnid *Dicloeopella borealis* suggests a Middle Albian age approximately equivalent to the Hulcross and Harmon shales of the Peace River area (J.H. Wall, pers. comm., 1989). As previously indicated, the spore assemblages from the uppermost Beaver Mines Formation and Lynx Creek Member strata of the Mill Creek Formation correspond with those reported by Singh (1971) for the

uppermost Harmon and Cadotte members of the Peace River area of northwestern Alberta. However, the angiosperm assemblages are more diverse than those reported by Singh (1971) for Harmon and Cadotte strata; angiosperms are consistent with those reported by Doyle and Robbins (1977) for their zones IIb_2 and perhaps the base of zone IIb_3, and to the Cheyenne Formation assemblages reported by Ward (1986). These rocks reaffirm the inference that the uppermost Beaver Mines and Lynx Creek Member strata are conformable and of late Middle Albian and perhaps earliest Late Albian age.

Interpretation

The sediments of the Lynx Creek Member represent the progradation of two and possibly three shoreline successions in a highstand systems tract that conformably overlay the Beaver Mines Formation and formed in the late Middle Albian or earliest Late Albian. The outcrop on the Carbondale River contains a lower, poorly defined coarsening-upward succession overlain by a flooding surface. Cycles 2 and 3 coarsen upward from sandstone and siltstone of the offshore-transition through to lower shoreface zones. The low-angle, divergent laminae in the sandstone are interpreted as indicating foreshore deposits. The sandstone is capped by rooted siltstone and shale. The top of the third cycle passes into terrestrial deposits containing soils.

At Mill Creek, the coarsening-upward cycles are interpreted as representing the more distal portions of those at Carbondale River. In addition, marine and brackish-water dinoflagellates and acritarchs, including *Micrhystridium* sp., *Balmula tripenta*, Ceritaceae *sensu* Bint 1986, *Nyktericysta davisii*, *Pseudoceratium interiorense*, *Apteodinium granulatum*, *Odontochitina singhii* and *Tasmanites* sp. are relatively common and diverse at Mill Creek.

The predominance of hummocky cross-stratification and wave ripple laminae at Mill Creek and Carbondale River indicates sedimentation primarily by wave processes. The orientation of wave-ripple crests in fine-grained sandstone and coarser grained sediment can be used to establish the general trend of local shorelines (Leckie, 1988; Leckie and Krystinik, 1989). As such, the orientation of wave-ripple crests occurring within the Lynx Creek Member indicates a local shoreline trend of north-northeast–south-southwest. Sole marks from the bases of hummocky beds indicate sediment transport to the southeast.

The thicknesses of the shoreface successions at Carbondale River are 9 and 4 m, which is comparable to the thickness of low-energy shorefaces on the northeast coast of the United States (McCubbin, 1982; Howard and Reineck, 1981). It is in marked contrast to the high-energy shoreface deposits of the modern California coast (Howard and Reineck, 1981), the Albian Falher Member (Leckie and Walker, 1982; Leckie, 1986; Cant, 1984) or Campanian/Santonian Milk River shoreline (Meijer Drees and Mhyr, 1981; Cheel and Leckie, 1990) all of which which may be up to 30 m thick. Consequently, the shorelines of the Lynx Creek Member are interpreted as having been somewhat low-energy forms such as exist along the modern Georgia coast.

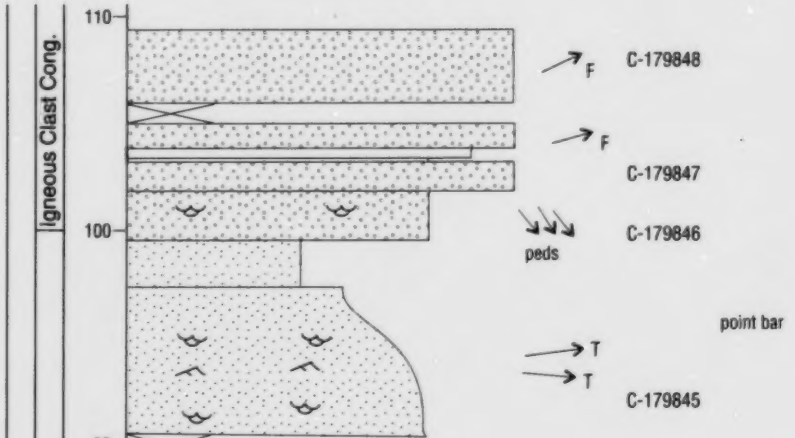


Figure 14. *Measured part of type section of Bruin Creek member on Livingstone River near mouth of Bruin Creek (MC 7) (for legend, see Appendix 2).*

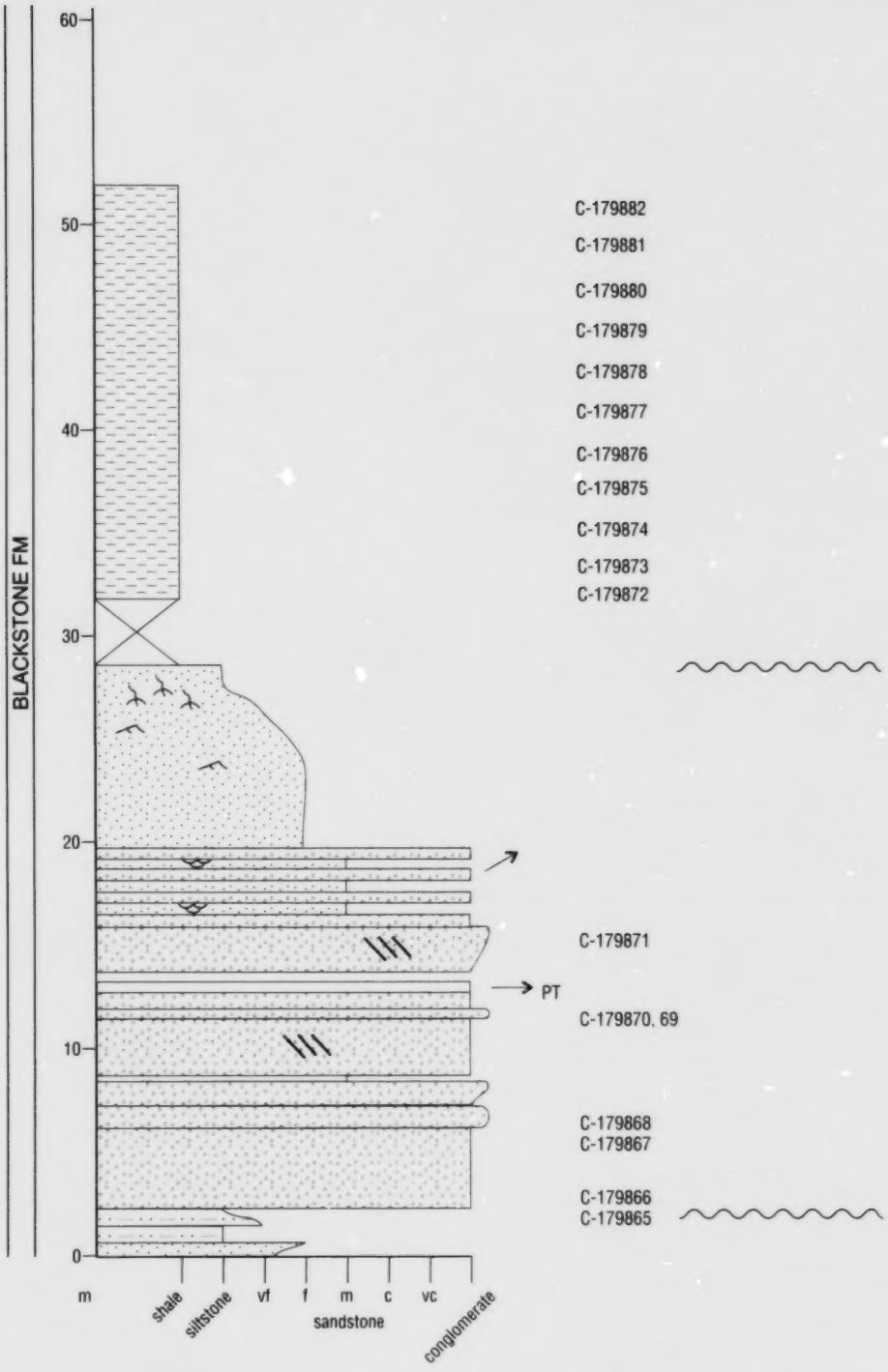


Figure 14 offset. *Measured section 30 m from section represented in Figure 14 (for legend, see Appendix 2).*

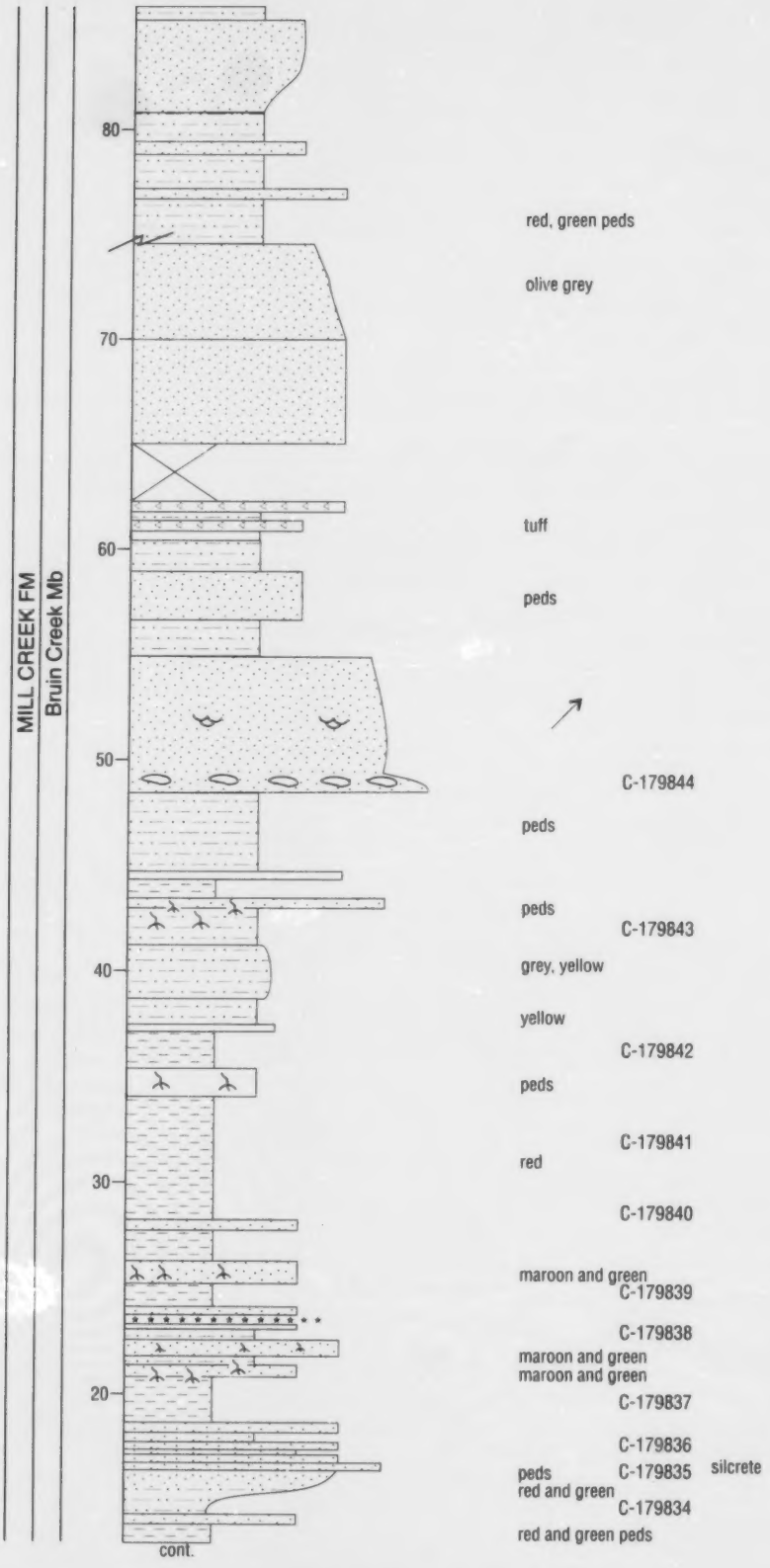


Figure 14. *Measured section continued.*

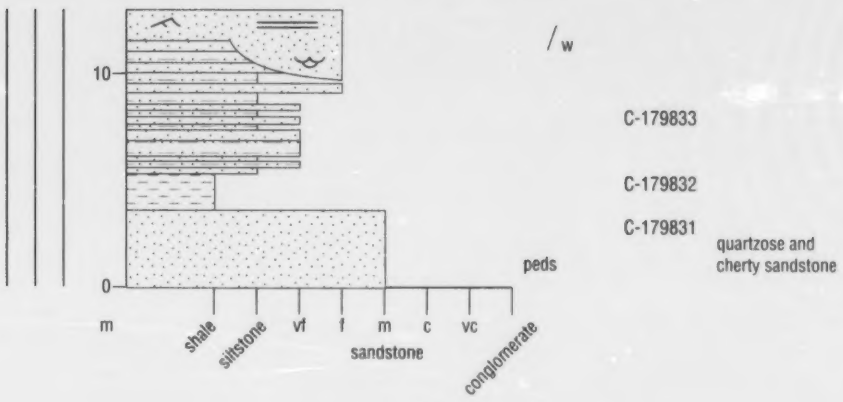


Figure 14. *Measured section continued.*

Tintinnids in the Lynx Creek Member are indicative of a brackish-marine environment (J.H. Wall, pers. comm., 1989), as is the broken and disarticulated macrofossil assemblage (J.W. Haggart, pers. comm. 1990). The Mill Creek sections contain some foraminifera and fewer tintinnids than the section on Carbondale River. The Carbondale River section contains no foraminifera. Dinoflagellates and acritarchs at Carbondale River are neither common, nor diverse. Assemblages containing small quantities of *Nyktericysta davisii*, *Balmula tripenta*, *Micrhystridium* sp. and *Pseudoceratium interiorense* suggest a restricted and probably brackish-marine setting. The Carbondale River section is interpreted as having been deposited in a more proximal or landward direction.

Bruin Creek Member

Definition, distribution, and description

The Bruin Creek Member of the Mill Creek Formation is named after Bruin Creek, near which the type section outcrops (MC 7, 9; Fig. 1). The type section of the Bruin Creek Member (Fig. 5, 14) is located on the Livingstone River, approximately 150 m south of the junction with Bruin Creek on the east side of the forestry trunk road. The Bruin Creek Member occurs throughout the Rocky Mountain Foothills from the Carbondale River, north to the Livingstone River. Reconnaissance observations indicate that the member may extend farther north, at least to the Bow River, and possibly beyond. Subsurface equivalents of the Bruin Creek Member in southwestern Alberta include the marine and nonmarine strata of the Bow Island Formation.

Reference sections for the Bruin Creek Member at the Carbondale River, Mill Creek, and Ma Butte sections (Fig. 1) illustrate some of the variability of the Bruin Creek Member, including: 1) the variable presence of an igneous-pebble conglomerate (Leckie and Craw, 1995; Leckie and Krystinik, 1995), 2) outcrop showing the top of the Bruin Creek Member in contact with the volcanic strata of the Crowsnest Formation rather than the marine shale of the Blackstone Formation, and, 3) the lower contact of the Bruin Creek Member in direct contact with the Beaver Mines Formation. Other incomplete sections are illustrated and described in Appendix 2. The geology of the region surrounding the type section is shown in Douglas (1950); the geology of the reference section is shown in Price (1962).

The Bruin Creek Member varies from a thickness of 87 m at Mill Creek to 133 m at Bruin Creek (Fig. 5). The basal contact of the Bruin Creek Member is a sharp, irregular surface that cuts underlying strata (Fig. 5, 15b). The lowermost beds consist of medium- to coarse-grained cherty sandstone and, locally, conglomerate, which rest erosionlly on Lynx Creek or Beaver Mines strata.

Internally, the Bruin Creek Member is restricted to include interbedded cherty sandstone with abundant rock fragments, varicoloured mudstone, conglomerate, and ash. It is in part laterally equivalent to the Crowsnest Formation and contains igneous-pebble conglomerate previously referred to as the McDougall-Segur conglomerate (Leckie and Craw, 1995; Leckie and Krystinik, 1995).

The McDougall-Segur Conglomerate is an informal term applied to Bruin Creek Member strata consisting of laterally discontinuous beds of conglomerate up to 30 m thick and 3 km wide. Internally, McDougall-Segur beds are rich in igneous and volcanic clasts with lesser amounts of chert and quartzite set in a medium-grained, greenish grey, arkosic matrix.

In the Crowsnest Pass area, the conglomerate occurs near the top of the Blairmore Group and within the Bruin Creek Member. An informal reference section to illustrate the

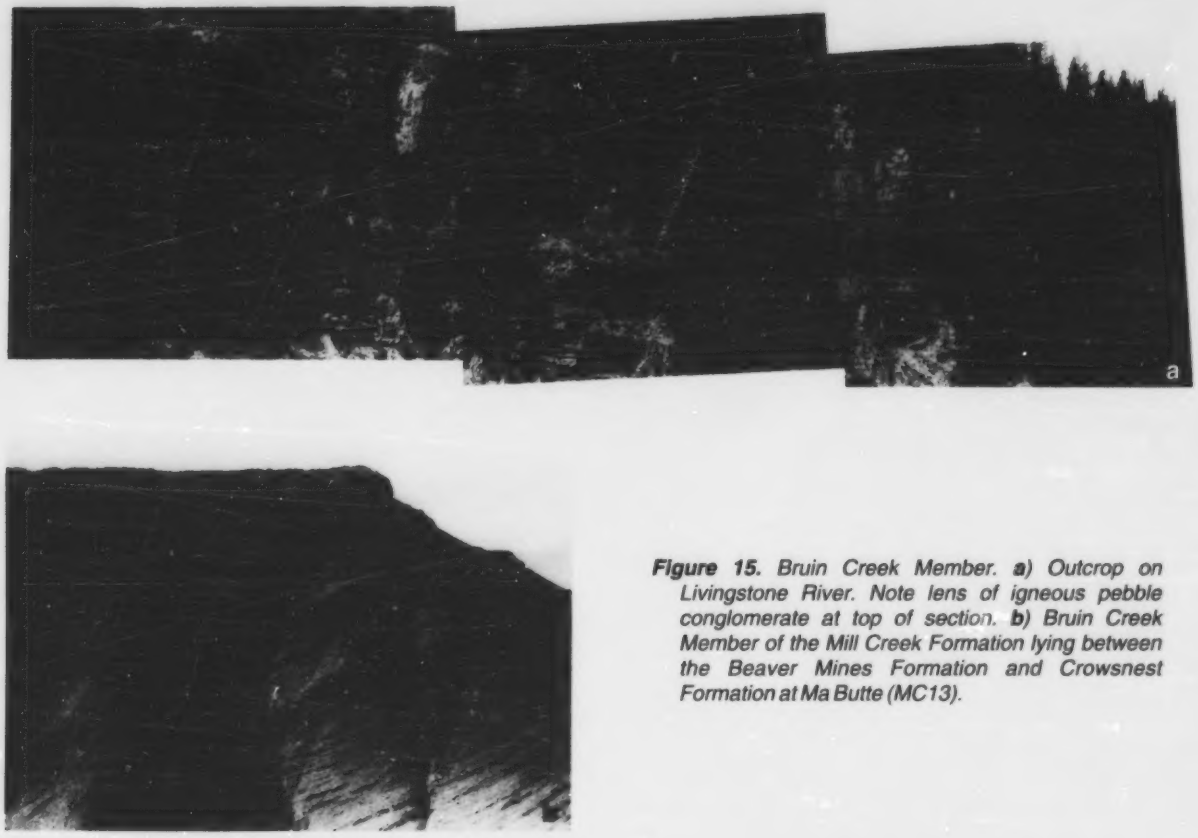


Figure 15. *Bruin Creek Member.* ***a)*** *Outcrop on Livingstone River. Note lens of igneous pebble conglomerate at top of section.* ***b)*** *Bruin Creek Member of the Mill Creek Formation lying between the Beaver Mines Formation and Crowsnest Formation at Ma Butte (MC13).*

facies of the conglomerate is designated at the type section for the Bruin Creek Member at Bruin Creek (Fig. 8, 14). At several localities such as Ginger Hill (MC 4, Appendix 2), York Creek (MC 5, Appendix 2), and the Frank Slide Interpretive Centre (MC 11, Appendix 2), it is not possible to ascertain the exact stratigraphic position of the conglomerate because reliable markers are not present. However, farther north near Turner Valley, the conglomerate occurs lower in the section, as much as 21 m below the top of the Blairmore Group (Hume, 1939).

Lithology and sedimentology

Type section: Livingstone River (MC 7, 9)

The basal unit of MC 7, and one which is not fully exposed, is a medium-grained, quartzose and cherty Beaver Mines Formation sandstone at least 2.5 m thick (Fig. 14).

Lying sharply upon the basal sandstone is up to 45 m of variegated red, grey, and maroon shale, siltstone, and fine grained sandstone. Thinner beds on the order of 50 cm or less in thickness are invariably pedogenically altered and may contain rhizocasts (Fig. 7B). Thicker sandstone beds, a metre or more in thickness, are lensoid in shape and contain trough and tabular crossbeds. Sandstone beds tend to become thicker and more common in the upper part of this unit.

Beginning at about 48.5 m in MC 7, the Bruin Creek Member comprises about 50 m of predominantly thick-bedded, fine- and medium-grained sandstone, separated by thin, variegated red and grey siltstone beds and volcanic ash. Sandstone beds up to 7 m thick, fine upward from a shale-clast or chert-pebble conglomerate to fine- or medium-grained sandstone. Sedimentary structures are predominantly trough cross-stratification in sets ranging from 20 to 80 cm. The trough crossbeds indicate a generally easterly flow (Fig. 16). Siltstone beds, normally less than 1 m thick, are crumbly and pedogenically altered.

Sharply overlying the sandstone and in erosional contact lie 9 m (17.5 m at MC 9) of clast supported, massive and imbricated, igneous-pebble conglomerate (the McDougall-Segur Conglomerate). Individual beds are typically about a metre in thickness. Clast imbrications indicate an easterly flow (Fig. 14, 16). The top 4.5 m of the conglomerate consist of interbedded sandstone and conglomerate with beds 0.25

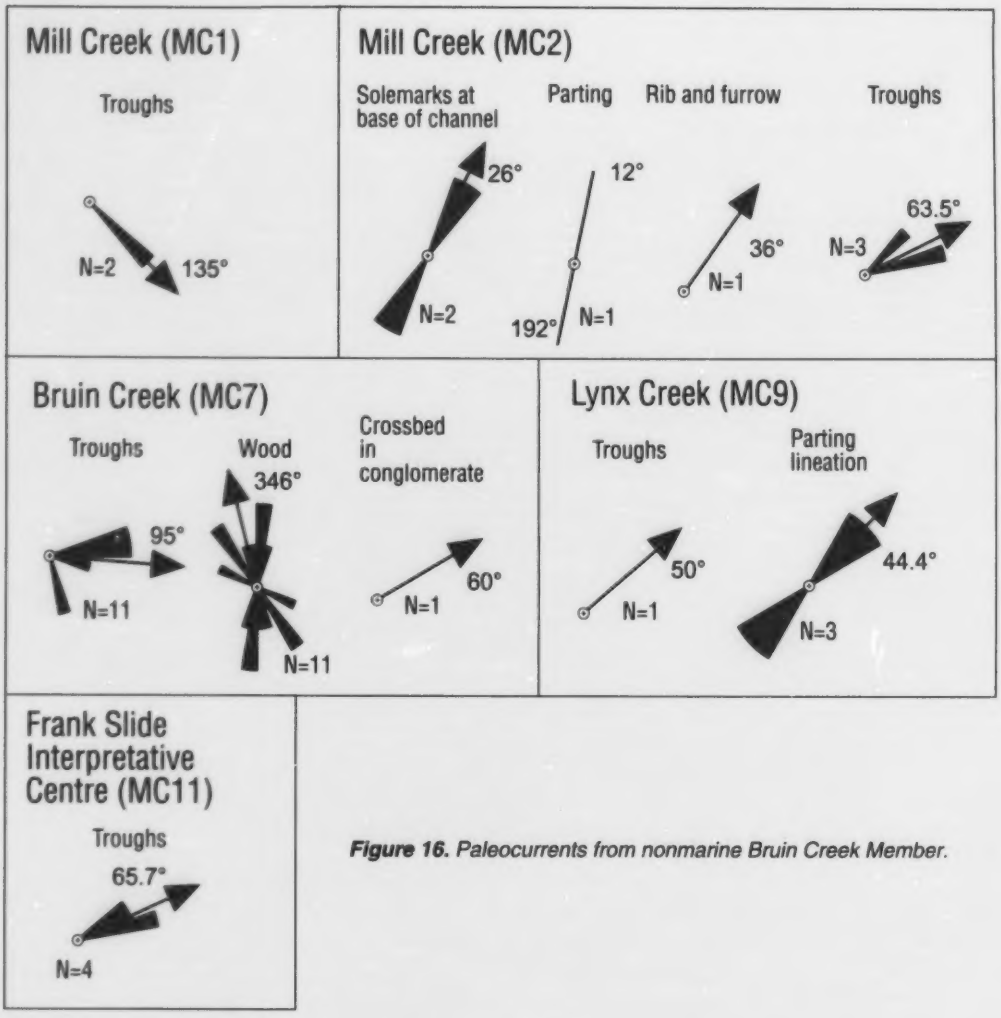


Figure 16. *Paleocurrents from nonmarine Bruin Creek Member.*

to 1 m thick. Lenses of medium-grained sandstone decimetres thick and up to a few metres long are common. The conglomerate typically pinches out laterally into medium- to coarse-grained sandstone. Intraformational mudstone clasts up to 2 m in size occur locally at the base of the conglomerate. Tree casts are present but are rare. Stratification within the conglomerate consists predominantly of crude parallel bedding with bed sets up to 40 cm in thickness. Pebble clasts are typically well imbricated. Planar-tabular crossbeds, commonly with sets up to 50 cm thick, are defined by clasts lying on the foresets. Pressure solution features are a characteristic of the conglomerate.

The uppermost unit of the Bruin Creek Member at the type locality consists of about 9 m of fine-grained sandstone lying with a sharp, yet conformable contact on conglomerate beds (Fig. 14). The sandstone is by and large massive with faint ripples and rooted horizons near the top.

Reference section: Carbondale River (MC 6)

The basal unit of the Bruin Creek Member, at 176 m in the section, is a 2.5 m lens of medium- to very coarse-grained, pebbly sandstone resting on scoured Lynx Creek Member strata. A chert-pebble conglomerate may be locally present, with clast sizes ranging from 1 to 5 cm. Clasts are subangular to subrounded; shale clasts to 5 cm are common. Wood debris is locally present at the base of the sandstone and in some places it may be abundant. Elsewhere in the section, abundant tree casts are oriented north–south (Fig. 14).

The basal sandstone fines upward through several stacked, lensoid sandstone bodies about 2 m thick and into 9 m of rooted siltstone and shale. Two 6 m thick, fine- and medium-grained, massive sandstone beds, separated by 2 m of very fine sandstone and siltstone, lie on a sharp contact with underlying strata. Above the sandstone beds lie about 13 m of variegated siltstone with thin beds, less than 1 m

thick, of fine-grained sandstone. The upper 2 m of the continuously exposed section consists of 3 m of medium-grained, trough-crossbedded sandstone. Above this point (221 m in the complete Carbondale River section) the outcrop is by-and-large covered. The next exposures, many metres upstream and from about 320 to 340 m in the section, are thick bedded volcanic strata of the Crowsnest Formation.

Reference section: Mill Creek Section (MC 1, 2, 3)

The basal unit of the Bruin Creek Member is found at about 126 m in MC1 (Fig. 6). It consists of 20.4 m of medium- to coarse-grained, pebbly sandstone resting on scoured Lynx Creek Member strata. Chert pebbles may be present locally. Clast sizes range from 1 to 5 cm; clasts are subangular to subrounded.

Sedimentary structures consist predominantly of trough cross-stratification in sets ranging from 20 to 80 cm. Wave ripples have a 3 cm wavelength and 3 mm amplitude and are oriented north–south (Fig. 14). The trough crossbeds and ripples indicate a generally easterly flow (Fig. 16). The upper portion of the sandstone may contain in situ vertical roots and peds.

Strata overlying the thick basal sandstone consist of 42 m of interbedded sandstone, siltstone and shale. The sandstone is fine to coarse grained and commonly pinches out laterally. Upward within the member, as the sandstone becomes more arkosic, sedimentary structures are more difficult to discern. Trough crossbeds persistantly indicate an easterly paleoflow (Fig. 16). On Mill Creek (MC 2, at 116 m, Appendix 2), a coarse-grained sandstone has a conglomeratic lag with volcanic and chert clasts to 6 cm. Siltstone and shale beds are olive green, grey, and maroon coloured. Vertical roots, pedogenic slickensides and peds are common. In all of the Mill Creek sections, the upper few tens of metres of the Bruin Creek Member contain isolated beds of volcanic debris consisting of feldspar lathes within a siltstone groundmass.

Reference section: Ma Butte (MC 13)

On Ma Butte (MC 13, Fig. 8, 15b), strata of the Bruin Creek Member directly overlie the Beaver Mines Formation, the Lynx Creek Member having been eroded out. The basal unit of the Bruin Creek Member is a 1.5 m thick chert-pebble conglomerate that pinches out laterally. Clasts are subangular to subrounded and range from 1 to 5 cm in diameter. Shale clasts to 5 cm are common. The basal conglomerate fines upward to very fine-grained sandstone. Trough cross-stratification, in sets ranging from 20 to 80 cm, is the predominant sedimentary structure. The upper portion of the sandstone is rippled. Strata overlying the basal sandstone consist of interbedded sandstone, siltstone, and shale. The sandstone is fine to coarse grained, several metres to tens of metres thick and commonly pinches out laterally. A stacked, or composite sandstone body (MC 13, Fig. 8, 305–337) is 32 m thick. Upward, within the member, as the sandstone becomes more arkosic, sedimentary structures are more difficult to discern. Trough crossbeds indicate an easterly paleoflow (Fig. 16). Siltstone and shale beds are olive green, grey, and maroon coloured. Vertical roots, pedogenic slickensides, and peds are common.

Age and paleontology

Bruin Creek Member strata rest sharply and unconformably on the Lynx Creek Member or Beaver Mines Formation strata. Palynomorph assemblages from these beds are, in general, poorly preserved. The dominant taxa in these pedogenically altered strata are the psilate spores *Cyathidites minor, Deltoidospora hallii* and *Laevigatosporites ovatus*. Other spores are corroded and broken and difficult to identify. Nevertheless, two spore taxa, *Cibotiidites robustus* and *Cicatricosisporites* sp. cf. *C. crassiterminatus*, appear to have some biostratigraphic value. *Camarozonosporites ambigens* was not found; it is either very rare or absent in these rocks.

One sample, (C-179927, Fig. 10, 11) from the Carbondale River, contains a diverse assemblage of pollen and spores. If taken as representative of the flora contained in the Bruin Creek Member, the new angiosperms appearing in the flora include *Liliacidites tectatus, Retimonocolpites peroreticulatus, Phimopollenites augathellaensis, P. pannosus, Retitrescolpites kempiae, Rousea marthae, Striatopollis paranea* and *Tricolporoidites* sp., among other tricolpate taxa. Many specimens, nominally assigned to *Tricolpites micromunus* and other tricolpate species, are tricolporoid.

Dinoflagellate cysts are sporadically distributed throughout these strata. It is not clear whether these beds contain reworked marine strata or are, in fact, marine deposits modified by pedogenic processes.

Arguments for the age of the Bruin Creek Member rely on the large assemblage of angiosperms, including tricolporoid forms and the spore *Cibotiidites robustus*. Together they suggest that the lower part of the Bruin Creek Member is younger than the Lynx Creek Member – that is to say, equivalent to the Bow Island Formation in the subsurface farther east (Burden, unpublished) and the lower part of subzone IIb_3 of the Atlantic Coastal Plain (Doyle and Robbins, 1977). Subzone IIb_3, considered early Late Albian, is thought to be a more complex biozone in Western Canada where several distinctive floras are recognized. Lower Bruin Creek strata may contain the earliest subzone IIb_3 floras. The

following section on palynology outlines problems and issues in understanding subzone IIb_3 biostratigraphy.

Interpretation

The apparent lateral continuity of the lowermost sandstone and an absence of siltstone and clay may suggest that the river that deposited the sandstone was not meandering, or if it was, may have been a low-sinuosity system.

Strata above the basal sandstone exhibit a marked increase in rock fragment content, and the quartz and chert content decreases. Siltstone and clay represent floodplain and overbank deposits that were pedogenically altered. Sandstones were deposited by high-sinuosity meandering rivers. The water table was probably relatively low, or fluctuated, because only minimal organic matter has been preserved.

In most measured sections, Bruin Creek Member rocks are devoid of sedimentary structures. Peds are common in mudstones; sandstones rarely exhibit fining-upward successions with very rare crossbedding.

Palynomorph recovery is not good in these pedogenic strata, but assemblages are by and large terrestrial in composition. Rare, and commonly corroded, Cretaceous dinoflagellates and acritarchs in Bruin Creek strata at Mill Creek suggest either a nearshore setting with episodic marine incursions or, more likely, erosion and reworking of underlying Lynx Creek and Beaver Mines strata. A terrestrial fluviatile and pedogenic setting similar to the Beaver Mines Formation, but of Late Albian age, is inferred for these rocks. Detailed interpretations of the paleosols are in McCarthy et al. (1977a,b; 1998).

Discontinuous beds of conglomerate rich in igneous and volcanic clasts with lesser amounts of chert and quartzite set in a medium-grained, greenish grey, arkosic matrix were first reported by Rose (1917) from York Creek, near Coleman. Since that time there have been several reports from along the Rocky Mountain Foothills from Montana to as far north as the Trans-Canada Highway near Calgary (Hume, 1938; Beach, 1943; Hage, 1943; Allan and Carr, 1947; Douglas, 1950; Clow and Crockford, 1951; Norris, 1958; Price, 1962; Urbatt, 1988; Leckie and Krystinik, 1995; and Leckie and Craw, 1995). In the Turner Valley area, the McDougall-Segur interval was described as a locally oil-bearing conglomeratic sandstone, containing chert, quartz and, most significantly, igneous pebbles (Hume, 1938, 1939; Anderson, 1951), and lying within the upper part of the Blairmore Group. Norris et al. (1965) proposed that all igneous-bearing conglomerates within the Blairmore Group be referred to as belonging to the McDougall-Segur interval. Norris et al. (1965) suggested that the McDougall-Segur Conglomerate represented a single depositional event and could be used as a correlatable time line. This conclusion was criticized by Mellon (1967), who suggested that igneous-bearing conglomerates occur at different stratigraphic intervals in the middle and upper Blairmore Group. Urbatt (1988) indicated that the McDougall-Segur Conglomerate was found only in the Beaver Mines Formation. However, our results show that a distinctive conglomerate commonly occurs at the top of the Mill Creek Formation.

Leckie and Krystinik (1995) argued that the name "McDougall-Segur Conglomerate" does not conform to the Code of Stratigraphic Nomenclature and should be abandoned. They argued that a more appropriate informal descriptor such as "igneous-clast conglomerate" be used.

The pebble- to boulder-sized clasts of the McDougall-Segur interval (Fig. 17) consist of grey chert, grey, pink and green quartzite, argillite, igneous, and volcanic lithologies (Norris et al. 1965). In conglomerates identified by Urbatt (1988), the plutonic clasts consist of leucoalkali–granites, leucogranite, leucogranodiorite, leucoquartz–monzonite, leucoquartz–diorite and syenite; volcanic clasts are predominantly leucorhyolite and leucodacite (Urbatt, 1988). At the Bruin Creek locality, the conglomerate contains green clasts of volcanic debris similar to that of the Crowsnest Volcanics.

The conglomerate is typically clast-supported with a medium-grained sandstone matrix. The matrix consists of chloritic, quartz–chert–feldspar sandstone and can be variably classified as feldspathic litharenite, lithic arkose or arkose (Norris et al., 1965). Feldspars are sodic plagioclase and sericitized and kaolinitized orthoclase. There is considerable lateral variation in clast size and bedding is poorly defined or nondiscernible. Where bedding is evident, individual beds are up to 40 cm thick and vary from poorly sorted to well sorted; some beds may contain clasts several decimetres in size, which are abuptly overlain by beds containing clasts with a maximum size of a few centimetres. Other than the occurrence of large intraformational clasts at the base of the conglomerate, there is no discernible vertical grain size variation.

Detailed petrographic studies have indicated that the McDougall-Segur Conglomerate was sourced in the Selkirk and Purcell mountains of southeastern British Columbia, possibly the Nelson and Kaskanax batholiths (Anderson, 1951; Mellon, 1967; Norris et al., 1965; Urbatt, 1988; Craw and Leckie, 1996). The Kaskanax Batholith has been dated at 173± 5 Ma (Parrish and Wheeler, 1983) and the Nelson Batholith at 164 Ma (Nguyen et al., 1968), dates comparable to the 174 to 113 Ma K–Ar dates obtained by Norris et al. (1965) from seven pebbles in the McDougall-Segur Conglomerate. Urbatt (1988) considered that the variations

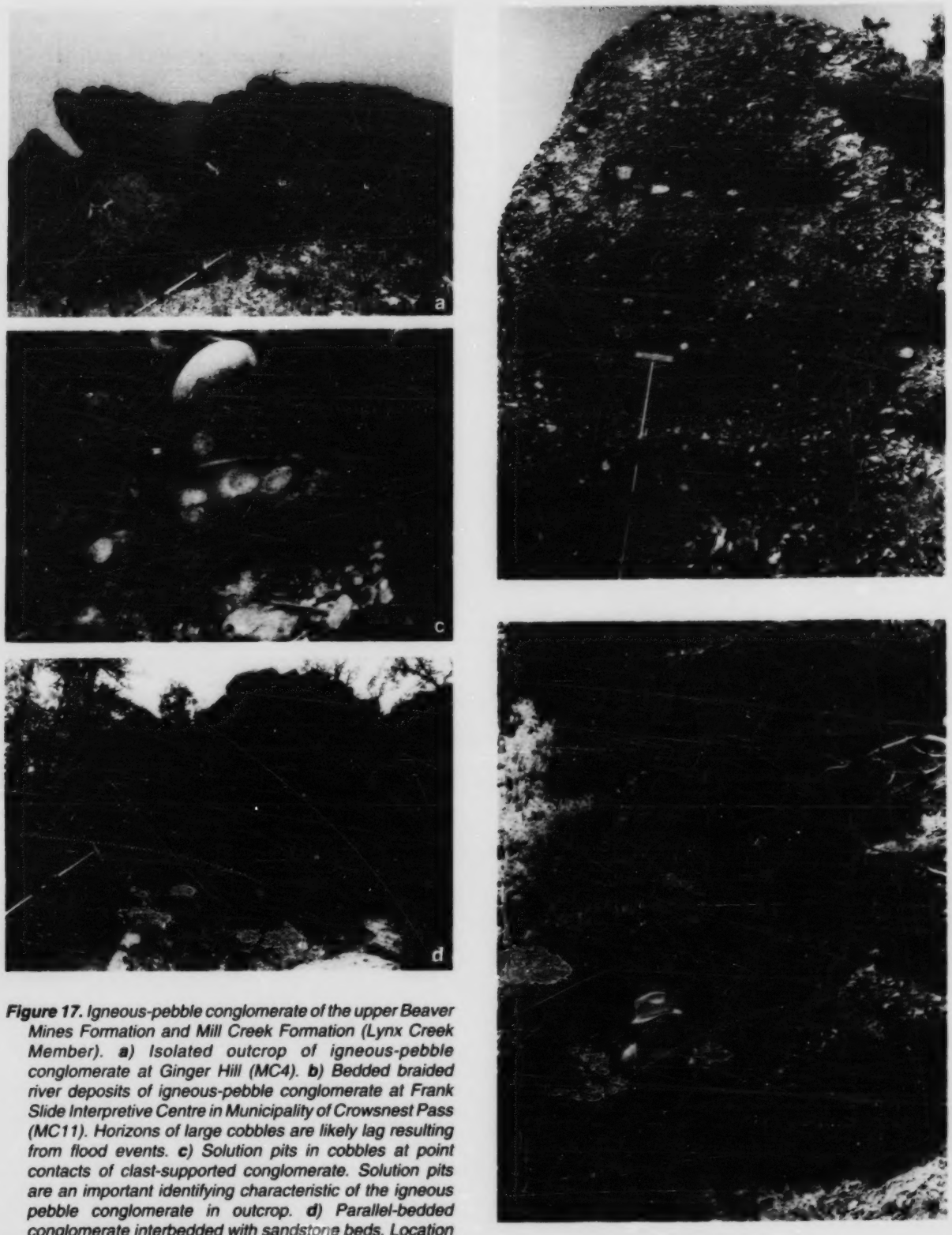


Figure 17. *Igneous-pebble conglomerate of the upper Beaver Mines Formation and Mill Creek Formation (Lynx Creek Member).* ***a)*** *Isolated outcrop of igneous-pebble conglomerate at Ginger Hill (MC4).* ***b)*** *Bedded braided river deposits of igneous-pebble conglomerate at Frank Slide Interpretive Centre in Municipality of Crowsnest Pass (MC11). Horizons of large cobbles are likely lag resulting from flood events.* ***c)*** *Solution pits in cobbles at point contacts of clast-supported conglomerate. Solution pits are an important identifying characteristic of the igneous pebble conglomerate in outcrop.* ***d)*** *Parallel-bedded conglomerate interbedded with sandstone beds. Location is on Livingstone River near Bruin Creek.* ***e)*** *Outcrop of igneous-pebble conglomerate.*

in quartzite content within the McDougall-Segur Conglomerate were the result of differences in exposure of the Kootenay Terrane in the source areas. Because of the similarities in composition, Urbatt considered the volcanic and plutonic clasts to be genetically related to the same magmatic events.

Norris et al. (1965) considered the igneous-pebble conglomerate previously referred to as the McDougall-Segur conglomerate to be at least partly correlative with the Crowsnest Formation. They came to this conclusion because of a perceived association of the igneous-pebble conglomerate with the sedimentary strata derived from the Crowsnest Formation. Norris et al. (1965) indicated that outcrops existed where the igneous-pebble conglomerate was interbedded with the Crowsnest Formation. However, these outcrops were not described and this relationship has not been observed by us.

Crowsnest Formation

Definition, distribution, and description

The name Crowsnest Formation is retained for thick agglomerate, volcaniclastic debris flows, and ash-fall deposits at the top of the Blairmore Group (Hage, 1943; Price, 1962; Norris, 1964). The Crowsnest Formation is considered as a stratigraphic unit within the Blairmore Group following Mellon and Wall (1963) and Mellon (1967). The type section is that given by Price (1962), Norris (1964) and measured in detail by Adair (1986) for Crowsnest strata exposed in the Coleman Thrust along Highway 3 and along the railroad west of Coleman (Fig. 1, 18). A reference section was designated by Mellon (1967) for the formation in rocks exposed at Mill Creek that are distal deposits of the Crowsnest volcanic event; they are not typical of the thick, volcaniclastic strata located near Coleman (Ricketts, 1982; Adair, 1986). A second reference section has been assigned by Norris (1964) to the exposure at Ma Butte, but was not described by him. A geological map of the regions surrounding the reference section on Mill Creek and the type section near Coleman is in Price (1962).

The lower contact of the Crowsnest Formation interfingers with clastics of the Bruin Creek Member (Norris, 1964; Pearce, 1970; Adair, 1986). The upper contact with the Blackstone Formation is sharp, with up to 37 m of relief (Norris, 1964). At Mill Creek (MC 1, Fig. 6) the upper contact is represented by 1 m of parallel-laminated, coarse-grained sandstone. On Lynx Creek (MC 8, Table 1), the contact is marked by 2.5 m of well-sorted, fine-grained, parallel-laminated sandstone. Elsewhere on Mill Creek, (MC 2 and MC 3, Table 1) the contact is represented by black marine shale of the Blackstone Formation lying directly on distal facies of the Crowsnest Formation

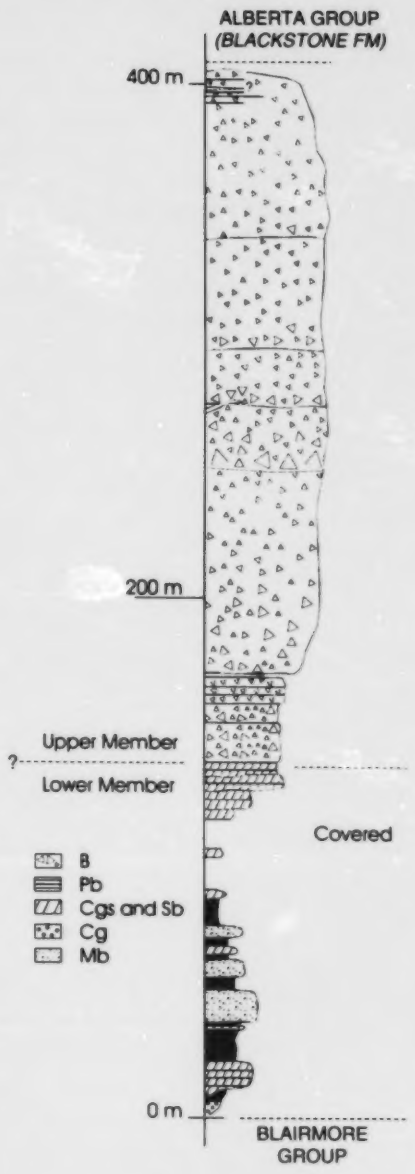


***Figure 18.** Measured section of the Crowsnest volcanics along Highway 3 west of Coleman (after Adair, 1986).*

interbedded with the nonmarine Bruin Creek Member. At Willowby Ridge, in the Crowsnest Pass, strata of the Bruin Creek Member have a mineralogy representative of the Crowsnest Formation as far as 150 m below the first occurrence of unreworked Crowsnest Formation (Adair, 1986). Adair suggested that this and the presence of conglomerate clasts in the basal deposits indicate volcanic activity elsewhere, before deposition of volcanic sediments took place near Coleman.

The Crowsnest Formation has a maximum thickness of between 426 and 488 m (Price, 1962; Pearce, 1970; Norris, 1964) where exposed on the Coleman Thrust and on Ma Butte. Formation thickness, bed thickness, and clast size generally decrease away from this area (Pearce, 1970). The Crowsnest Formation has been mapped in the Foothills as far north as Hidden Creek at about 50° N latitude and as far south as Mill Creek (Price, 1962; Norris, 1964). However, in the more distal regions, the distribution of volcanics is patchy. For example, on Mill Creek, more than 80 m of volcaniclastic strata are poorly exposed at section MC 1 (Fig. 5, 6), but at sections MC 2 and MC 3 (Appendix 2), only isolated volcanic beds were observed. In the latter two sections several tuffaceous, bentonitic, and volcaniclastic beds with numerous paleosols provide evidence of siliciclastic nonmarine sedimentation.

The lower part of the Crowsnest Formation is trachytic and contains abundant sanadine phenocrysts, garnet, and pyroxene (Pearce, 1970). The formation consists primarily of tuff, lapilli tuff, thin- to thick-bedded ash, agglomerates and volcanic sandstone (Adair, 1986; Fig. 18). The upper part of the Crowsnest Formation has a high sanadine, analcite, and garnet content, with accessory rock fragments. It is primarily a pyroclastic breccia and agglomerate. Blairmorite and analcite are generally more common in the southern part of the outcrop area (Pearce, 1970). Black melanite garnet is common in the formation and can be used as an indicator of the lower gradational contact with the Bruin Creek Member. Volcanic clasts are up to several metres wide and on Ma Butte may weigh up to 15 (short) tons (Pearce, 1970).

Age and paleontology

On Mill Creek, the late Cenomanian and early Turonian index fossils *Dunveganoceras* of the Sunkay Member and *Watinoceras* and *Inoceramus labiatus* of the Vimy Member occur in shales of the Blackstone Formation (Stelck et al., 1972; Glaister, 1959). Both the Vimy and Sunkay members thin considerably over the Crowsnest Formation and the Sunkay Member is not present near Coleman (Adair, 1986). *Inoceramus labiatus* lies directly on the Crowsnest Formation near Coleman (Glaister, 1959; Mellon, 1967). Away from the Coleman area, to the south and north, the thickness of the interval between the top of the Crowsnest Formation and *I. labiatus* increases. In addition, regional subsurface correlations show that the Fish Scale Zone pinches out westward toward the Crowsnest Pass area.

The uppermost strata examined in this study include samples from the Crowsnest Formation and the Blackstone Formation on Mill Creek. Crowsnest strata are barren; Blackstone strata are fully marine deposits containing amongst many other dinoflagellates, the species *Wallodinium bidigitatum* and *Wigginsiella grandstandica*. Both taxa occur in Cenomanian and Turonian strata. Blackstone pollen and spore taxa, including common *Camarozonosporites ambigens* and *Rugubivesiculites rugosus* and rare *Senecotetradites* sp., confirm the general shift in vegetation toward different assemblages of gymnosperms and relatively advanced angiosperms. The end of Crowsnest volcanism can have occurred no later than late Cenomanian.

Bell (1956) assigned an Albian age to the Crowsnest Formation based on flora collections in the area. Melanite garnets in the Crowsnest Formation are reportedly similar to garnets within the Viking Formation in south-central Alberta (M. Dean *in* Adair, 1986). This is consistent with conclusions by Amajor (1985) who inferred that the ash beds in the Viking Formation were derived from the Crowsnest Formation. Early radiometric dates of the Crowsnest Formation using K/Ar techniques range from 93.9 Ma to 101 Ma (Folinsbee et al., 1957; Folinsbee et al., 1961). A recent U/Pb date of 103± .5 Ma was obtained by 40/39 dating of a single sanadine crystal from the volcanics exposed along Highway 3 at Coleman (J. Obradovitch, pers. comm., 1996) indicating a Middle to Late Albian age for the Crowsnest Formation. Bruin Creek Member palynomorphs from beds below volcanic ash show volcanism can be no older than Late Albian.

Interpretation

The volcanoes that produced the Crowsnest Formation were on an inland floodplain centred near Coleman and were probably of high relief (Glaister, 1959; Norris 1964; Mellon, 1967; Pearce, 1970; Adair, 1986). The Ma Butte, Coleman, and George Creek areas, where maximum sediment thicknesses also occur (Pearce, 1970; Ricketts, 1982), were probably source areas or pipes for the volcanic detritus.

The magma chamber may have been a hydrous alkaline trachyte (Pearce, 1970), which resulted from crustal melting at about 25 to 35 km depth. Pearce (1970) interpreted the volcanic material as consisting of agglomerates and tuffs (partly water reworked), volcanic sandstone, volcanic flows, and dykes. Ricketts (1982) indicated that many of the beds had characteristics of laharic breccias (volcanic debris flows). Many beds contain primary sedimentary structures that Ricketts (1982) interpreted as representing alluvial deposition by short-lived streams, although Adair (1986) argued that many of the structures are similar to volcanic surge deposits found on modern volcanoes. Many of the textures (plastic deformation structures, suture boundaries, and baked margins) present in the volcanics suggest that emplacement took place at elevated temperatures, although there is not always evidence of welding (Adair, 1986).

Nosean trachyte flow rocks are common. Blairmorite occurs as blocks and bombs or as lithic tuffs. Rock fragments make up to 73 per cent of the Crowsnest Formation (Adair, 1986). Near Coleman, Adair (1986) estimated that 90 per cent of the Crowsnest deposits was pyroclastic in origin, the balance being primarily lavas and volcanogenic sediments. Pearce (1970) proposed that the volcanism was primarily the explosive type, with only minor flows. Adair (1986) suggested that the style of Crowsnest volcanism changed from highly to moderately gas-charged-type eruptions for the lower Crowsnest Formation, producing air-falls, ignimbrites and lava flows. The upper Crowsnest eruptive style was one of poorly gas charged and dome-building eruptions, which resulted in dome growth, collapse and/or disintegration, producing block flows. Following volcanism and erosion, marine muds of the Turonian-age Viney Member onlapped onto the topographiclly high volcanic pile (Norris, 1964).

ECONOMIC MINERAL POTENTIAL

The Crowsnest Pass–Oldman River area is reputed to have been the area in which the legendary lost Lemon Gold Mine was located (Riley et al., 1968). The source of the alleged gold deposits has been attributed to gravels in modern streams in this area, paleo-placer deposits, and, more recently, from the volcanic rocks of the Crowsnest Formation. Forty-six samples from the upper Beaver Mines, Mill Creek, and Crowsnest formations, including the McDougall-Segur Conglomerate, were commercially processed for gold and an additional 30 elements using ICP techniques by Loring Laboratories Ltd., Calgary. Results are summarized in Table 2. For the McDougall-Segur Conglomerate, samples were provided from the sandstone matrix between the pebbles. Many samples contain insignificant amounts of gold. However, several samples contain measurable amounts ranging from 10 to 80 ppb. For comparison, gold content of modern and ancient sedimentary strata and volcanic rocks is shown (from Boyle, 1979) in Table 3.

Silver content ranges from 0.1 to 4.7 ppm, with a mean of 0.3 ppm, which is comparable to the average of 0.3 ppm for all sedimentary rocks (Boyle, 1979)

For comparison, gold and silver derived from highly productive sandstone and conglomerate fields in the Witwatersand, South Africa, average 8 ppm Au and 0.8 ppm Ag; in Tarkwa, Ghana, 10 ppm Au and 0.5 Ag; and in Jacobina, Argentina, 15 ppm Au and 1 ppm Ag.

To be economical (in 1979), gold content of sedimentary deposits had to be about 0.1 ppm (Boyle, 1979). Several samples from the Mannville Group in southwestern Alberta excede this cutoff and there is considerable potential for localized enrichment of placer gold at unconformities such as the base of the Bruin Creek Member and channels or valleys associated with the McDougall-Segur Conglomerate. Gold concentrations may also be possible in the winnowed lag deposit associated with the transgression of the Blackstone Formation. Furthermore, most of the clasts in the McDougall-Segur Conglomerate were derived from Mesozoic volcanic and plutonic rocks in the Omineca Crystalline Belt of central British Columbia, specifically the Nelson and Kaskanax batholiths (Urbatt, 1988). The batholiths and surrounding regions have had a long history of extensive gold-quartz vein deposits and were a likely source of placer material during the Cretaceous (Boyle, 1979). Again, for comparison, the average abundance of gold and silver in granitic rocks is 4 ppb for gold and 0.04 ppm for silver (Levinson, 1980). Gold and silver concentrations in the McDougall-Segur Conglomerate are higher by up to an order of magnitude, possibly indicating a concentrating effect.

More detailed assessments of the economic potential of the interval are in Leckie and Craw (1995) and Craw and Leckie (1996).

REGIONAL CORRELATION OF UPPER BLAIRMORE PALYNOMORPH ASSEMBLAGES

Regional correlations (Fig. 19) based on literature reviews are fraught with problems linked to variations in the consistency of data collection. The most obvious problem is misidentification of fossils. Some taxa vary subtly in morphology and careful measurements are often required to separate species. In other instances, advances in taxonomy indicate that some species may be divided into two or more species; resolution of new species from previously published reviews is nearly always impossible unless one re-examines the original data. Stratigraphy and correlations are not necessarily correct [see for example, the revision of Singh's (1971) data in the Peace River area]; the ability to resolve details of the rock record improves as researchers continue to work in an area. While useful, the older paleontological literature must be continuously re-examined, evaluated and updated on a sample-by-sample basis if we are to successfully test new stratigraphic models.

Central Alberta

Norris (1967) examined strata from the Grand Rapids Formation of the Mannville Group and the Joli Fou, Viking, and "upper shale unit" of the lower Colorado Group in the Anglo-Home-C. and E. Fort Augustus No. 1 (7-29-55-

Table 2
Metal values for outcrop samples

Sample #	Section	Formation/Mb.	Au ppb	Mo ppm	Cu ppm	Pb ppm	Z ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	Fe %	As ppm	U ppm	Th ppm	Sr ppm	Cd ppm
C-178410	MC 1	Lynx Creek	10	6	5	11	9	0.1	4	1	28	0.74	7	5	1	2	1
C-178421	MC 1	Bruin Creek	0	1	6	11	45	0.1	10	5	481	1.04	8	5	1	116	1
C-178422	MC 1	Bruin Creek	0	1	14	15	86	0.1	16	6	109	1.45	3	5	2	8	1
C-178428	MC 1	Crowsnest	0	1	9	27	42	0.1	1	6	513	1.76	2	5	1	468	1
C-178430	MC 1	Crowsnest	0	1	30	16	38	0.1	3	4	325	1.47	7	5	3	91	1
C-178434	MC 2	Bruin Creek	0	9	10	11	41	0.3	16	5	322	1.43	29	5	1	77	1
C-178437	MC 2	Bruin Creek	50	1	9	14	56	0.2	18	5	421	1.54	9	5	3	91	1
C-178439	MC 2	Bruin Creek	10	1	12	35	85	0.1	13	9	714	2.81	2	5	2	99	1
C-178441	MC 2	Bruin Creek	0	1	16	17	31	0.1	3	5	660	2.24	52	5	2	84	1
C-178442	MC 2	Bruin Creek	45	1	5	19	47	0.1	2	3	374	1.45	4	5	3	155	1
C-178448	MC 2	Bruin Creek	10	1	5	16	10	0.1	2	1	144	0.47	2	5	9	37	1
C-179813	MC 4	Bruin Creek ?	0	1	33	10	79	0.2	32	13	831	4.26	14	5	5	35	1
C-179814	MC 4	igneous pebble	0	1	39	4	87	0.4	20	12	955	4.10	22	5	3	49	1
C-179815	MC 4	igneous pebble	20	1	43	9	92	0.1	25	14	906	4.71	21	5	2	39	1
C-179818	MC 5	igneous pebble	15	1	22	6	79	0.2	17	9	821	4.30	13	5	2	25	1
C-179819	MC 5	igneous pebble	0	1	24	12	91	0.2	20	9	504	4.00	15	5	2	23	1
C-179831	MC 7	Bruin Creek	25	1	9	9	19	0.4	6	3	53	0.52	4	5	1	3	1
C-179835	MC 7	Bruin Creek	0	1	15	14	69	0.1	13	5	88	0.68	2	5	1	8	1
C-179844	MC 7	Bruin Creek	0	1	13	15	61	0.1	17	10	686	2.44	14	5	1	20	1
C-179845	MC 7	Bruin Creek	0	1	11	11	75	0.1	18	9	384	2.10	74	5	2	55	1
C-179846	MC 7	igneous pebble	0	1	11	13	51	0.2	14	5	1363	1.97	12	5	3	74	1
C-179847	MC 7	igneous pebble	0	1	9	12	34	0.1	9	3	2240	1.06	12	5	2	111	1
C-179848	MC 7	igneous pebble	10	1	11	8	45	0.1	6	2	10252	1.44	2	5	2	124	1
C-179863	MC 8	Bruin Creek	0	1	5	9	41	0.2	5	3	530	1.59	5	5	3	147	1
C-179864	MC 8	Bruin Creek	0	3	7	10	13	0.1	4	2	30	1.72	12	5	2	23	1
C-179866	MC 9	igneous pebble	0	1	20	19	90	0.4	19	10	2310	2.65	15	5	3	85	1
C-179867	MC 9	igneous pebble	0	1	18	11	54	0.2	13	4	1848	1.59	4	5	3	86	1
C-179869	MC 9	igneous pebble	0	1	20	9	39	0.2	7	4	2531	2.10	6	5	4	233	1
C-179870	MC 9	igneous pebble	40	2	7	669	100	4.7	11	6	115	1.70	260	5	5	24	1
C-179871	MC 9	igneous pebble	10	1	31	12	80	0.2	18	8	822	3.57	22	5	5	67	1
C-179889	MC 11	Bruin Creek	0	7	15	9	74	0.1		10	470	2.83	15	5	1	20	1
C-179885	MC 10	igneous pebble	10	1	22	9	56	0.2	19	7	416	2.17	11	5	3	20	1
C-179890	MC 11	Bruin Creek	0	1	20	10	67	0.2	18	8	576	3.10	11	5	2	129	1
C-179892	MC 11	igneous pebble	0	1	30	11	94	0.3	19	10	628	4.64	25	5	2	57	1
C-179893	MC 11	igneous pebble	0	2	63	10	122	0.3	26	12	709	6.20	25	6	3	25	1
C-179901	MC 12	Bruin Creek	20	3	7	7	42	0.1	12	4	2276	0.93	20	5	1	60	1
C-179902	MC 12	igneous pebble	0	1	16	18	87	0.3	9	5	1129	3.26	19	5	5	30	1
C-179903	MC 12	igneous pebble	0	1	5	15	55	0.1	4	2	892	1.90	2	5	1	39	1
C-179904	MC 12	Bruin Creek	80	1	4	15	48	0.1	5	3	1200	1.16	2	5	9	115	1
C-179918	MC 13	Beaver Mines	0	1	23	11	84	0.1	23	9	506	3.54	2	5	2	184	1
C-179922	MC 13	Bruin Creek	0	2	11	14	87	0.3	28	5	153	1.23	20	5	1	32	1
C-179923	MC 13	Bruin Creek	0	8	9	13	64	0.1	14	4	556	1.13	210	5	2	205	1
C-179924	MC 13	Bruin Creek	0	9	2	13	4	0.5	3	1	30	0.67	12	5	1	162	1
bottom		Crowsnest	0	1	70	16	31	0.1	1	1	820	1.11	2	5	3	2244	1
middle		Crowsnest	10	1	220	66	156	0.2	1	11	1308	4.63	11	8	18	769	1
top		Crowsnest	10	1	249	61	135	0.2	1	11	1344	4.89	7	5	17	576	1

Table 3
Worldwide comparisons of metal values

Formation (no of samples)	Au Range ppb	Au Mean ppb	Ag Range ppm	Ag Mean ppm
upper Beaver Mines (1)	0	0		0.1
Lynx Creek Formation (1)	10	10		0.1
Bruin Creek Formation (22)	0–80	11.4	0.1–0.5	0.17
igneous pebble conglomerate (18)	0–40	5.5	0.1–4.7	0.45
Crowsnest Formation (5)	0–10	4	0.1–0.2	0.14
Sediment or rock type				
Terrigenous sediments				
Baltic Sea	0.1–5.4	3		
Black Sea	2–24	6		
Mediterranean Sea	1.1–9	3.8		
Atlantic Ocean	0.6–4.2	1.3		
Alluvial placers	<10–200,000			0.1–20
Sandstone, arkose, conglomerate and sedimentary breccia	0.2–430	57		0.2
Witwatersand conglomerates	400–230,000	800		0.8
All sedimentary rocks	0.1–2,500	40.3		0.3
Volcanic sediments	0.5–15	4.2–14		

21W4) wells. His was the first study to report angiosperm pollen from the Early Cretaceous of Alberta. However, inasmuch as this study was a pioneering effort, parts of this work have become dated; regional correlations of his terrestrial palynomorph floras can only be made in a general way (Fig. 19).

Rocks from the Fort Augustus well are dated from microfossil biostratigraphy (Mellon and Wall, 1963; Wall *in* Norris, 1967). Marine strata of the Grand Rapids Formation immediately above the Clearwater Shale contain the *Marginulinopsis collinsi–Verneuilinoides cummingensis* subzone (late Early Albian); the Joli Fou Formation lies within the *Haplophragmoides gigas* zone (early Late Albian); and the "upper shale unit" of the lower Colorado carries elements of the *Miliammina manitobensis* zone (late Late Albian). The ages for the upper part of the Grand Rapids Formation (Upper Mannville) and the Viking Formation are interpolated from foramifera data.

Norris's palynomorphs from the Grand Rapids Formation (Norris, 1967) are dominantly bisaccates and schizaealean taxa; no angiosperms were reported. Taxa include *Microreticulatisporites uniformis*, *Appendicisporites erdtmanii*, *Concavissimisporites punctatus*, *C. imisporites variverrucatus*, *Impardecispora apiverrucata*, *I. trioreticulata*, *Pilosisporites trichopapillosus*, *P. verus*, *Plicatella crimenensis*, *Triporoletes reticulatus*, *Equisetosporites* sp., *Januasporites spiniferus* and *Couperisporites complexus*. This assemblage has many taxonomic elements in common with the assemblage from the Beaver Mines Formation of this study and the *Retimonocolpites crassatus–Retimonocolpites peroreticulatus* zone (late Barremian to earliest Albian) of Alberta and Montana (Burden, 1984). Greater precision is not possible without additional angiosperm data.

The Joli Fou Formation in the Fort Augustus well contains the angiosperm taxa *Clavatipollenites minutus*, *Tricolpites minutus*, *T. vulgaris*, *Tricolpites sagax*, *Striatopollis paranea*, *Rousea georgensis* and *Rousea prosimilis*. These taxa are now thought to be relatively long ranging (Doyle and Robbins 1977; Ward 1986) first appearing together in late Middle and early Late Albian strata. The Joli Fou terrestrial palynomorph assemblage (including the spores) is broadly similar to an impoverished assemblage from the top of the Beaver Mines Formation. However, in our study, there is one taxon, *Striatopollis paranea*, which is confined to the Bruin Creek Member, suggesting a relationship with those beds. Joli Fou shale was deposited in an open-marine setting, away from terrestrial influences; foraminifera place the Joli Fou Formation within the *Haplophragmoides gigas* zone of the early Late Albian.

The Viking Formation and the "upper shale unit" have the spore *Camarozonosporites ambigens* and the gymnosperm *Rugubivesiculites rugosus*. In addition, the gymnosperm *Sequoiapollenites pusillus* and angiosperms *Retimonocolpites textus* and *Cupuliferoidaepollenites parvulus* are found in the "upper shale unit". These species (and other angiosperms) occur together in the uppermost part of the Bow Island Formation and overlying Colorado shale of southern Alberta (Burden, unpublished). Singh (1971) reported this assemblage of taxa farther north in the Shaftesbury Formation.

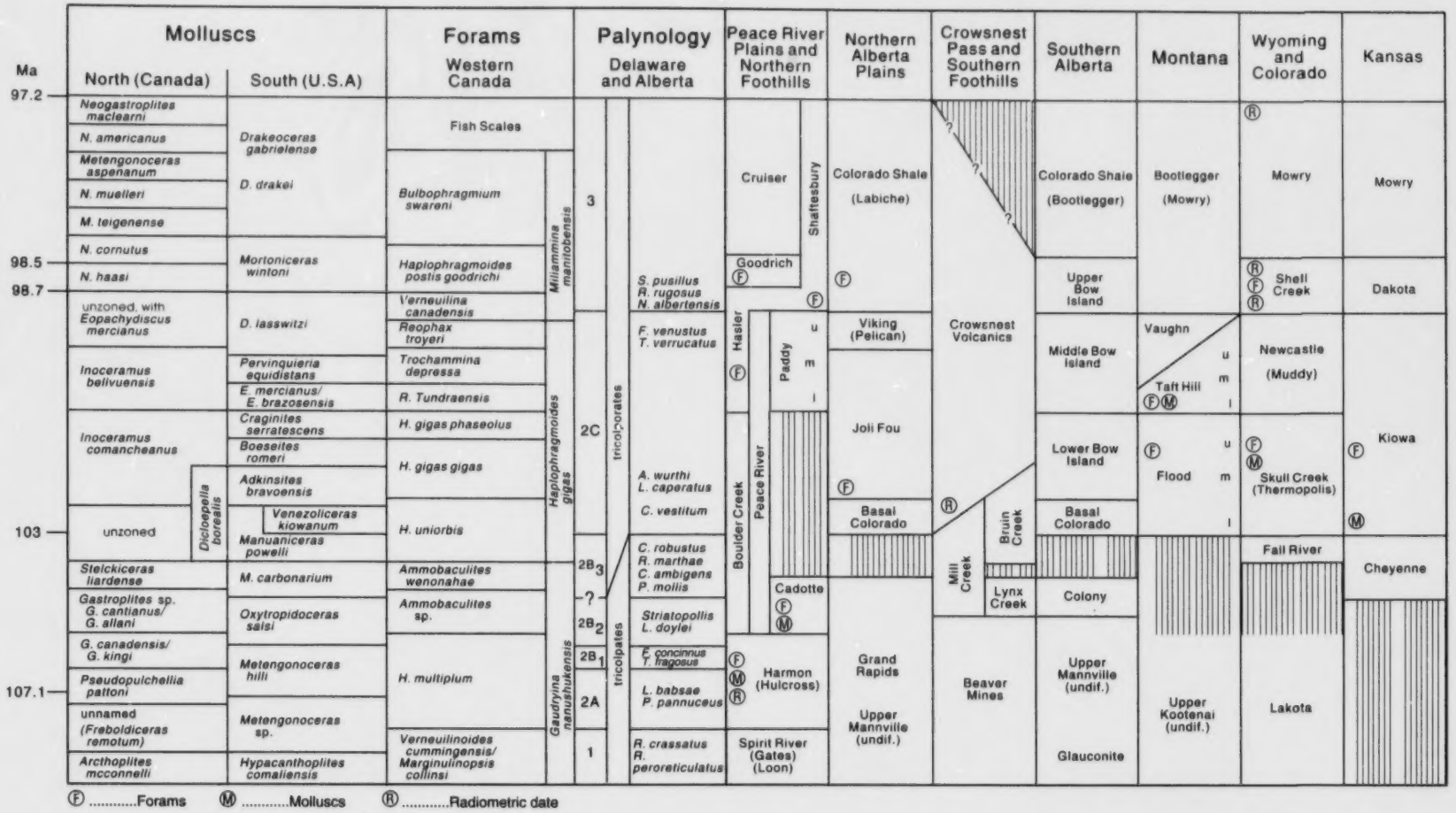


Figure 19. *Regional biostratigraphic correlations.*

Camarozonosporites is very rare in the Lynx Creek Member. There was only one specimen discovered in the section on the Carbondale River; it is common in the Blackstone Formation on Mill Creek. Likewise, *Rugubivesiculites rugosus* is restricted to the Blackstone Formation on Mill Creek. Hedlund and Norris (1968) reported *Sequoiapollenites pusillus* in late Middle Albian strata from Oklahoma; another report of *Sequoiapollenites pusillus* suggests this species appeared in Alberta in the Cenomanian (Singh, 1983).

Peace River

The Peace River area is but one of a very few localities in Alberta where independent evidence for age in a long section is available. Data compiled by Singh (1971) for this area have formed a standard for palynologists working on Albian strata.

Singh (1971) selected his sections from localities that were measured and analysed by Wickenden (1951) and Stelck et al. (1956). The data presented in Singh's work is remarkable for its detail. Since publication in 1971, no one has, to our knowledge, systematically dissected and re-examined this extraordinary database. This is surprising, considering the the fact that Singh's research was completed at a time when there was little information on the stratigraphy of the Peace River area and concepts in facies and sequence modelling of strata were virtually unknown.

An increase in petroleum exploration and development in Western Canada in the last 20 years has resulted in a great deal more information being available for the stratigraphic succession analysed by Singh (Leckie, 1989; Leckie and Singh, 1991). From this new work, subtle yet significant differences in the interpretation of regional lithostratigraphy and biostratigraphy indicate that some of the biostratigraphy reported by Singh (1971) should be reinterpreted.

Rocks of the upper part of the Spirit River Formation (Loon River Formation of Singh) and in the lower shales (particularly the bentonitic shales) of the Harmon Formation (reference sections 6, 8, of Singh, 1971) are dominated by abundant and diverse gymnosperm taxa. Common species include *Araucariacites australis*, *Cedripites canadensis*, *C. cretaceus*, *Cerebropollenites mesozoicus*, *Podocarpidites canadensis* and *P. multesimus*. Spores, particularly the schizaealean taxa *Cicatricosisporites* and *Appendicisporites*, are relatively abundant and diverse. Important schizaealean taxa include *Appendicisporites cristatus*, *A. spinosus*, *A. erdtmanii*, *Cicatricosisporites australiensis*, *C. minor*, *Cicatricososporites phaseolus*, *Concavissimisporites punctatus*, *Contignisporites cooksonae*, *C. glebulentus*, *Disaltriangulatisporites perplexus*, *D. irregularis*, *Klukisporites areolatus*, *K. foveolatus*, and *Pilosisporites trichopapillosus*. Other common spore taxa include *Baculatisporites comaumensis*, *Callialasporites dampieri*, *Cyathidites australis*, *Deltoidospora hallii*, *Foraminisporis wonthaggiensis*, *Foveosporites labiosus*, *Foveotriletes subtriangularis*, *Laevigatosporites ovatus*, *Ornamentifera baculata*, *Polycingulatisporites cicatricosus*, *P. reduncus*, *Todisporites minor*, *Antulsporites baculatus*, *Stoverisporites lunaris*, *Microreticulatisporites uniformis*, and *Verrucosisporites rotundus*. Angiosperms identified by Singh (1971) are neither common nor diverse; taxa include *Clavatipollenites hughesi*, *Tricolpites micromunus*, and, from the top of this interval, *Rousea georgensis*. This small number of angiosperms may simply be a function of offshore transport and preservation in marine strata; Burden (1984) observed a similar number of angiosperm taxa in older terrestrial strata.

Dinoflagellates and other marine algae are common in Spirit River and Harmon strata; unfortunately, none of the taxa identified by Singh (1971) is at this time significant for biostratigraphy. The Spirit River Formation contains diverse terrestrial palynomorph assemblages and thus differs slightly from the lower part of the Harmon Formation, which contains somewhat fewer terrestrial palynomorph taxa. The Spirit River–Harmon contact apparently marks the local (perhaps regional) top for many typical Early Cretaceous taxa. Species that disappear or become very rare in the Spirit River Formation include *Callialasporites dampieri*, *Concavissimisporites punctatus*, *C. variverrucatus*, *Distaltriangulatisporites irregularis/costatus*, *Foraminisporis wonthaggiensis*, *Klukisporites areolatus*, *Pilosisporites trichopapillosus*, *Polycingulatisporites cicatricosus*, *Stoverisporites lunaris*, *Microreticulatisporites uniformis*, *Appendicisporites erdtmanii*, *Cicatricososporites phaseolus*, and *Araucariacites australis*. Species that disappear or become very rare in the Harmon Member include *Foveosporites labiosus*, *Ornamentifera baculata*, *Reticulisporites elongatus*, *Antulsporites baculatus*, *Appendicisporites spinosus*, *Polycingulatisporites reduncus*, *Cedripites canadensis*, *C. cretaceus*, *Cerebropollenites mesozoicus*, *Classopollis classoides*, *Podocarpidites canadensis* and *P. multesimus*. While it is not yet demonstrable, it is suspected that some, and perhaps many species found randomly distributed and in small numbers in the overlying strata are reworked from older beds.

The upper part of the Spirit River Formation contains the *Marginulinopsis collinsi–Verneuilinoides cummingensis* microfaunal subzone of the *Gaudryina nanushukensis* zone, which is considered to be late Early Albian in age (Stelck et al., 1956; Stott 1982). The lower part of the overlying Harmon Member of the Peace River Formation carries the distinctive *Haplophragmoides multiplum* microfaunal subzone of the *Gaudryina nanushukensis* zone (Stelck et al.,

1956; Stott, 1982; Leckie, 1989), which is considered early Middle Albian in age. Obradovich (1993) reported an Ar/Ar date of 107.1 ±0.3 Ma from a bentonite in the upper 50 m of the laterally equivalent Hulcross Formation.

Strata from the upper part of the Harmon Formation (reference section 7, samples 7H1a, 7H1 and 7H2 *in* Singh, 1971) contain many of the taxa found in the underlying strata. However, in any given count reported by Singh (1971), the frequency and diversity of species is reduced to a point where many of the specimens are thought to be reworked from underlying strata, transported from some distance away or diluted by massive influx of fossils from another environmental setting (e.g., a nearby shoreline). Spore taxa that apparently increase in abundance include *Gleicheniidites senonicus* and *Lycopodiacidites canaliculatus*. In contrast to the spores, angiosperms become relatively abundant and diverse in Singh's samples from this interval. Angiosperm species found in addition to those reported from the underlying strata include *Foveotricolpites concinnus*, *Retitricolpites vulgaris*, *R. virgeus*, *Rousea prosimilis*, and *Cupuliferoidaepollenites* species. Singh (1971) also reported *Striatopollis paranea* from this interval, but it is unclear from his description and illustrations whether specimens belong to *S. paranea s.s.* or another species.

Strata of the Harmon Member are conformable with the overlying Cadotte Member (Leckie, 1989; Leckie and Singh, 1991). According to Stott (1982), the upper part of the Harmon Member is contained within the basal part of the *Ammobaculites* sp. subzone; Leckie and Reinson (1993) considered the Harmon and basal Cadotte to lie within the *Haplophragmoides multiplum* subzone. Thus, these rocks are either early Middle or middle Middle Albian.

Cadotte Member strata (Reference section 7, samples 7C4 to 7C11 of Singh, 1971) contain relatively abundant *Gleicheniidites senonicus*, *G. circiniidites* (including *G. bolchovitinae*) and *Impardecispora marylandensis*. In contrast, and with the exception of the earliest occurrence of *Rugubivesiculites reductus*, gymnosperms are neither common nor diverse. Important spore taxa making their earliest occurrence include sporadically distributed *Camarozonotriletes ambigens*, *Ornamentifera echinata* (called *Pilosisporites brevipapillosus* in this study) and *Ischyosporites disjunctus* and common *Retitriletes crassatus*. Angiosperm taxa are relatively common and diverse. In addition to the angiosperm assemblages continuing from the older, underlying strata, *Retitricolpites maximus* and *Tricolpites sagax* are introduced at this level.

In a general sense, the spore and angiosperm assemblages of the Cadotte Member correspond with those found at the top of the Beaver Mines Formation and in the Lynx Creek Member of the Mill Creek Formation. Cadotte strata in the Peace River area contain foraminifera of the *Ammobaculites* sp. subzone of the middle Middle Albian (Stott, 1982; Leckie, 1989).

Three samples from the top of the Cadotte Member (Reference section 7, samples 7C1, 7C2 and 7C3 of Singh 1971) contain a distinctive flora, unlike that found in the underlying beds, and relatively large numbers of *Asbeckiasporites wurthi* and *Lycopodiacidites caperatus*. Some spore species common in the Spirit River Formation and Harmon Member, and which apparently continue into the Cadotte Member, are last observed here. Included among these taxa are *Cicatricosisporites hughesi*, *Cyathidites australis* and *Klukisporites foveolatus*. Other spore and angiosperm taxa appear for the first time or increase in abundance in these "Cadotte" samples; the most significant species are frequent *Camarozonosporites ambigens*, rare *Striatopollis paranea*, and rare *Fraxinoipollenites venustus*. One dinoflagellate, *Chichaouadinium vestitum*, makes its entrance here. *Chichaouadinium vestitum* and *Camarozonosporites ambigens* are relatively common in the Bow Island Formation (Burden, unpublished).

The sharp contrast in the floral composition raises suspicions that the age for these three samples is not clear. Unfortunately, Singh's palynomorph samples come from strata no longer accessible. According to Wickenden (Wickenden's lithostratigraphic section 6; 1951), the beds that Singh sampled have a different style of bedding from underlying strata. In addition, clay content, concretions, and weathering patterns differ from those characterizing the underlying Cadotte Member. If one accepts Wickenden's lithostratigraphy and calls the rocks containing Singh's samples 7C1, 7C2, and 7C3 the Cadotte Member, then the foraminiferal biostratigraphy of the Cadotte Member points to a middle Middle Albian age for this distinctive floral assemblage. This age brings into question the biostratigraphic utility of the dinoflagellate *Chichaouadinium vestitum*, a widely recognized Late Albian marker for Western Canada.

These beds apparently mark a break where typical Cadotte Member taxa are replaced by species having affinities with the Paddy Member and other younger strata. Lower Paddy Member strata from the type section (Wickenden's section 2; Singh's section 5, samples 5P1, 5P2) contain a palynomorph assemblage nearly identical to the "Cadotte" samples 7C1, 7C2, and 7C3 in Singh (1971). Based on the inconsistencies in the lithostratigraphy and biostratigraphy, it is thought that the "Cadotte" siltstone containing Singh's samples 7C1, 7C2, and 7C3 are in fact lower Paddy Member; other Paddy strata (outlined below) are within the early Late Albian *Haplophragmoides gigas* zone.

Middle and upper Paddy Member sandstones (reference section 4 *in* Singh, 1971; lithostratigraphy from Leckie, 1989) contain the spore *Tappanispora* sp. cf. *Tigrisporites verrucatus*. Spores of *Gleicheniidites senonicus*, *Gleicheniidites* sp. cf. *G. circiniidites* (including *G. bolchovitinae*), *Impardecispora apiverrucata*, *I. marylandensis*, *Sestrosporites pseudoalveolatus*, *Camarozonosporites ambigens*, *Ornamentifera echinata* (*Pilosisporites brevipapillosus* of this study) and *Retitriletes crassatus* are relatively common. Less common spores include *Asbeckiasporites wurthi* and *Lycopodiacidites caperatus*. In addition to the angiosperms first reported from the underlying formations, *Retimonocolpites clavatus* appears in these rocks and *Fraxinoipollenites venustus* becomes relatively common. There are no biostratigraphically significant marine algae reported in Singh's study of this interval.

Tappanispora sp. cf. *Tigrisporites verrucatus* is a very distinctive taxon first reported by Singh (1971) and subsequently named by him (Singh, 1983). It appears to have a restricted range in the Paddy Member and other younger strata. In southern Alberta, this taxon first appears in the middle Bow Island coastal plain strata (Burden, unpublished) outlined by Reinson et al. (1994).

Paddy Member strata contain no diagnostic foraminifera. The bivalves *Inoceramus altifluminis* from an undisclosed location in the type section (Stelck, 1958) and *I. comancheanus* from lower Paddy strata (Leckie and Singh, 1991) indicate affinities with the early Late Albian *Haplophragmoides gigas* microfossil zone.

Shaftesbury Formation palynomorphs (reference section 2 of Singh, 1971) are closely comparable with the fossils from the upper Bow Island Formation through the Fish Scale zone (Burden, unpublished) and the Viking and the upper shale of the lower Colorado Group (Norris, 1967). Samples described by Singh (1971) contain the gymnosperm *Rugubivesiculites rugosus* and the tricolporate angiosperm *Nyssapollenites albertensis*. In addition to the tricolporate pollen, this zone is characterized by relatively large quantities of angiosperm pollen typified by *Tricolpites sagax*, *Cupuliferoidaepollenites parvulus* and *Retitricolpites vulgaris*. Spores, particularly those of *Impardecispora marylandensis*, decrease in abundance and diversity. Biostratigraphically significant marine algae indicating a late Late Albian age include the dinoflagellates *Apteodinium reticulatum*, *Oligosphaeridium totum*, *Luxadinium propatulum* and *Ascodinium verrucosum*.

The lower part of the Shaftesbury Formation contains elements of the *Verneuilina canadensis* subzone of the *Miliammina manitobensis* zone of the late Late Albian.

Manitoba

Playford (1971) examined the Swan River Formation in the type area along the Swan River in western Manitoba and in a borehole located in southeast Saskatchewan (S.W.P. Bredenbury 11A-36-22-1W2). Independent biostratigraphic evidence for the age of these rocks is lacking. The Swan River Formation lies unconformably on Middle Jurassic Ellis Group strata. Rocks lying conformably above the Swan River belong to the Skull Creek Member of the Ashville Formation; these beds contain agglutinated fauna of the *Haplophragmoides gigas* zone of the early Late Albian (McNeil and Caldwell, 1981).

Strata from the bottom of the Bredenbury borehole (below sample 1340) contain an assemblage of palynomorphs consisting of *Concavissimisporites variverrucatus*, *Foraminisporis asymmetricus*, *F. dailyi*, *F. wonthaggiensis*, *Kraeuselisporites hastilobatus*, *Pilosisporites verus*, *Stoverisporites lunaris* and *Triporoletes simplex*. Gymnosperms from this assemblage are diverse taxa consistently present in every sample. In contrast, angiosperms are not diverse; *Clavatipollenites hughesi*, *C. tenellis* and *Retimonocolpites peroreticulatus* are the only taxa reported (Playford 1971). Playford (1971) found no tricolpate pollen from these rocks. This assemblage is similar to that found in the Spirit River Formation of the Peace River area or perhaps the late Barremian through earliest Albian *Retimonocolpites crassatus–Retimonocolpites peroreticulatus* zone of Alberta and Montana (Burden 1984).

A major unconformity separates lower and upper Swan River strata in the Bredenbury borehole. The upper 24 m of the Bredenbury borehole and the type section for the Swan River Formation contain *Camarozonosporites ambigens*, *Asbeckiasporites wurthi*, *Rugubivesiculites reductus*, *Clavatipollenites hughesi*, *C. tenellis*, *Fraxinoipollenites venustus*, *Retitricolpites vulgaris*, *R. virgeus*, *Tricolpites sagax*, *T. parvus*, and *Striatopollis paraneus*. This assemblage is similar to that reported by Singh (1971) for lower Paddy strata. It may also correspond with lower Bow Island strata (Burden, unpublished) and the Joli Fou (Norris, 1967).

Atlantic Coastal Plain - Delaware and Maryland

Potomac Group strata of Maryland and Delaware have been intensely studied by palynologists for over 30 years. Two major studies by Brenner (1963) and Doyle and Robbins (1977) have resulted in a palynomorph zonation that tracks the early evolution and dispersal of angiosperms on the Atlantic Coastal Plain. These studies provide excellent

insights into the distribution and possible biostratigraphic position of angiosperms identified from other areas (see for instance Burden, 1984). One unfortunate aspect of the Atlantic Coastal Plain zonation lies in the lack of any independent evidence for age (Doyle and Robbins, 1977). Doyle and Robbins (1977) infer age from correlation with floras from other localities in North America and Europe.

Two palynomorph zones are recognized in the Potomac Group. Zone I contains abundant schizaealean spores, gymnosperms, *Cyathidites*, *Classopollis* and *Exesipollenites*. Less common taxa include *Stoverisporites lunaris* and *Equisetosporites* species. Angiosperms are neither common nor diverse; species include *Clavatipollenites hughesi*, *C. minutus*, *Clavatipollenites* sp. A (*Retimonocolpites crassatus in* Burden, 1984), *Liliacidites* sp. A (*L. inaequalis in* Burden, 1984), small *Liliacidites* sp. B, *Retimonocolpites peroreticulatus*, *Stellatopollis* sp. (with fine ornament) and, near the top of the zone, *Clavatipollenites tenellis*, *Retimonocolpites dividuus*, *Tricolpites crassimurus* and *Tricolpites* sp. A. The lower part of this assemblage corresponds with the late Barremian through earliest Albian CP zone of Burden (1984); tricolpate pollen in the upper part of Zone I suggest affinities with the Spirit River strata of the Peace River area (Singh, 1971) and perhaps also the lower parts of the upper Beaver Mines Formation, which were sampled for this study.

Zone II is divided into subzones using species bases (Doyle and Robbins, 1977); there are few extinctions among the taxa discussed in their study. Subzone IIa is marked by the entry of tricolpate grains closely related to *Retitricolpites vermimurus*, *Tricolpites albiensis*, *Tricolpites* (now *Rousea*) *georgensis*, *T. micromunus*, *T. sagax* and *Tricolpopollenites* (now *Cupuliferoidaepollenites*) *parvulus*. Spores appearing in subzone IIa include *Lophotriletes babsae* and *Perotriletes pannuceus*. This assemblage is similar to that reported for the lower part of the Harmon Formation of the Peace River area (Singh 1971). Doyle and Robbins (1977) believed zone IIa to be early Middle Albian; this is consistent with the age for the faunal zones reported for the Harmon Formation of Alberta.

Subone IIb is characterized by the loss of *Classopollis* and the schizaealean spores, and the appearance of *Cicatricosisporites patapscoensis*, *Cibotiidites robustus* and *Scopusporis spackmanii*. Also appearing somewhat higher in the section are the spores *Camarozonosporites ambigens* and *Rugubivesiculites reductus*. Gymnosperms and spores in the lower part of subzone IIb (Brenner's subzone IIb_1) correspond with the records for taxa in the upper Beaver Mines Formation and the Lynx Creek Member of the Mill Creek Formation of southern Alberta and the upper Harmon and Cadotte members of the Peace River area in northwestern Alberta.

Angiosperms identified by Doyle and Robbins (1977) indicate three informal divisions of subzone IIb. Subzone IIb_1 is defined by the entrance of tetrads of *Ajatipollis* sp., *Liliacidites* sp. E (similar to a slightly larger (25 µm) *L. tectatus*), *Stellatopollis barghoornii*, *Astropollis asteroides*, *Foveotricolpites concinnus*, *Retitricolpites fragosus*, *Rousea geranioides*, *R. prosimilis*, *Stephanocolpites fredericksburgensis* and *Tricolpites* sp. B. Many of the angiosperms reported in Doyle and Robbins (1977) subzone IIb_1 are found at the top of the Beaver Mines Formation and in the Lynx Creek Member of the Mill Creek Formation. Subzone IIb_1, thought to be Middle Albian in age (Doyle and Robbins, 1977), places a maximum age limit on these beds.

Subzone IIb_2 of Doyle and Robbins (1977) contains pollen tetrads of *Dicotetradites* sp. A, large (>40 µm) *Liliacidites* sp. F (now *L. doylei*) and *Liliacidites* sp. D. *Striatopollis* sp. A, *Tricolpites minutus* and near the top, *Striatopollis paraneus*. Subzone IIb_3 of Doyle and Robbins (1977) contains polycolpate grains, *Penetetrapites mollis* and tricolporoidate grains of *Tricolporopollenites triangulus*. Inasmuch as *Striatopollis* sp., *Penetetrapites mollis* and *Tricolpites minutus* are found in uppermost Beaver Mines and Lynx Creek strata, their presence alone should not be taken to indicate equivalence with either subzone IIb_2 or subzone IIb_3 of the Atlantic Coastal Plain. These taxa have been found elsewhere in North America in slightly different palynomorph assemblages (Hedlund and Norris 1968; Srivastava 1975; Ward 1986). Historically, *Striatopollis* sp. and *Striatopollis paranea* are not particularly well defined with respect to their morphology and distribution. *Penetetrapites mollis* is a very distinctive form from the Walnut Clay of Oklahoma (Hedlund and Norris, 1968). These beds are correlated with the *Manuniceras carbonarium* zone, which is approximately equivalent to the *Ammobaculites wenonahae* zone of Western Canada. Given species distribution patterns, it may not be possible to properly correlate Subzones IIb_2 and IIb_3 of the Atlantic Coastal Plain in Western Canada. Doyle and Robbins (1977) suggest the top of subzone IIb is early Late Albian. Thus, given that the first appearances of *Striatopollis* sp. and *Penetetrapites mollis* represent the true base for these taxa, the uppermost beds of the Beaver Mines Formation and the Lynx Creek Member of the Mill Creek Formation are probably latest Middle Albian in age.

In comparison with the Atlantic Coastal Plain study (Doyle and Robbins, 1977), the strata of the Bruin Creek Member are not clearly defined by their palynology. The diverse angiosperms, including some oroid forms, and the spore *Cibotiidites robustus* in the lower part of the Bruin Creek Member point to affinities with subzones IIb_2 and IIb_3 of the Atlantic Coastal Plain. An intriguing lack of *Camarozonosporites ambigens* in the Bruin Creek strata suggests equivalence with subzone IIb_2.

Subzone IIb_3 contains *Camarozonosporites ambigens* and probably corresponds with lower Bow Island (Burden, unpublished) and Paddy Member strata. Doyle and Robbins (1977) assigned an early Late Albian age to their subzone IIb_3; this is consistent with the faunal dates for the Peace River strata in Alberta.

Subzone IIc contains abundant *Rugubivesiculites rugosus*, *Scopusporis spackmanii*, *Lycopodiacidites* sp. and *Granulatisporites* sp. Some angiosperm taxa from underlying zones are apparently absent in subzone IIc. New additions include tricolporate pollen species *Tricolporidites subtilis*, *T. minimus*, *Tricolporopollenites distinctus* and *Tricolporidites* sp. A. Tricolporate pollen and *Rugbivesiculites rugosus* indicate subzone IIc correlates with strata equivalent to and above the upper part of the Bow Island Formation in southern Alberta (Burden, unpublished) and with lower Shaftesbury strata of the Peace River area (Singh, 1971). Doyle and Robbins (1977) believe subzone IIc is late Late Albian, which is consistent with the faunal ages from Alberta.

Cheyenne and Kiowa formations, Kansas

The Cheyenne and Kiowa formations of Kansas comprise fluviodeltaic sandstones and marine shales deposited as the Kiowa Sea spread north from the Gulf Coast (Ward, 1986). Cheyenne Formation rocks are thought to be late Middle Albian or early Late Albian in age. These rocks are overlain by Kiowa strata that contain the early Late Albian ammonites *Venezoliceras kiowanum* and *Adkinsites bravoensis*, and higher in the sections, the bivalves *Inoceramus comancheanus* and *I. bellvuensis* (Scott, 1970a, b). Bivalve zones from the middle and upper Kiowa Formation indicate affinities with the *Haplophragmoides gigas* zone and perhaps other Late Albian zones in Western Canada.

The angiosperms identified by Ward (1986) provide a useful and very detailed insight into taxa not reported in the studies of correlative strata in Western Canada. There are 83 species of angiosperm pollen in the Cheyenne and Kiowa formations (Ward, 1986). Many species occur in both formations, which led Ward (1986) to speculate that sampling intensity has a role to play in species distribution. This phenomenon, generally referred to as the Monograph Effect, is evident in many geological studies. Nevertheless, from his work, nine species are apparently restricted to the Cheyenne Formation, and 45 species to the Kiowa Formation.

Ward (1986) listed *Tricolpites fragosus*, *T. mitis*, *Tricolporidites minimus* and *T. nubiginus* as the most commonly occurring species restricted to the Cheyenne Formation. *Tricolpites fragosus* occurs in the upper Beaver Mines Formation and the Mill Creek Formation.

The most common species restricted to the Kiowa Formation are *Clavatipollenites minutus*, *Retimonocolpites dividuus*, *R. reticulatus*, *Retitrescolpites azemae*, *Rousea miculipollis*, *R. duplibaculata*, *R. marthae*, *Striatopollis paranea*, *Tricolpites albiensis*, *T. amplifissus*, *T. vulgaris*, *Tricolporidites eximus*, *Liliacidites doylei* and *L. kiowaensis* (Ward, 1986). *Clavatipollenites minutus*, *Retimonocolpites dividuus*, and *R. reticulatus* are relatively long-ranging taxa found in the upper part of the Beaver Mines Formation and in younger strata. *Rousea miculipollis* and *Liliacidites doylei* occur in Lynx Creek and younger strata. *Striatopollis paranea* and *Rousea marthae* are recorded from the Bruin Creek Member.

Ward (1986) made no mention of *Camarozonosporites* and *Asbeckiasporites* in his Cheyenne assemblages, although he (pers. comm. 1990) believes they are in the Kiowa Formation. The distribution of *Camarozonosporites* in the Cheyenne Formation is not clear (Ward, pers. comm., 1990); *Lycopodiacidites* and *Camarozonosporites* were not separated and a direct comparison with Alberta assemblages is not possible. According to Ward (1986), Cheyenne palynomorphs correlate with the upper part of subzone IIb of the Atlantic Coastal Plain; this may be subzones IIb_2 or IIb_3 of Doyle and Robbins (1977). Without a definite answer on *Camarozonosporites* and other spores in the Cheyenne Formation, and with other macrofossil (plant) evidence indirectly pointing to a late Middle Albian or an early Late Albian age for Cheyenne rocks (Scott 1970a, b; Scott and Taylor, 1977; Ward, 1986), Cheyenne correlations may include any or all of the upper Beaver Mines Formation, the Lynx Creek Member, and the Bruin Creek Member in Alberta.

In contrast to the enigma of the Cheyenne palynofloras, Kiowa assemblages are more readily compared with other described palynomorph suites. The Kiowa Formation contains several varieties of tricolporate pollen, pollen tetrads, and the gymnosperm *Rugubivesiculites rugosus*. These taxa show clear affinities with zone IIc of the Atlantic Coastal Plain and the Shaftesbury, Viking, upper Bow Island, and Colorado strata in Alberta.

Ward (1986, and pers. comm., 1990) has not resolved the stratigraphic distribution of *Rugubivesiculites rugosus* in the Kiowa Formation. Bivalve zones reported for the Kiowa Formation, while not definitive, suggest that either *Rugubivesiculites rugosus* is found only in the upper part of the Kiowa or *R. rugosus* is a more southerly distributed species that migrated into Alberta in the late Late Albian. The Kiowa Formation angiosperms identified from Mill Creek strata are not morphologically advanced taxa. They

are unlikely candidates as significant indicators for Upper Albian deposits. The lower part of the Bruin Creek Member can be no younger than pollen zone IIb_3 of Doyle and Robbins (1977).

SYSTEMATIC PALYNOLOGY

The stratigraphic distribution of all pollen, spores and algae identified during the course of this study is listed on the Mill Creek sections (in pocket). In addition, an alphabetical listing of fossils is given in Appendix 1.

Fossils are classified using the turma system of various authors as discussed in Burden and Hills (1989). Most specimens having broad ranges and conforming to original species descriptions are not discussed or illustrated. Species with relevance to local and regional biostratigraphy and paleoecology are discussed in the following paragraphs and illustrated. The number preceding each species refers to the corresponding number on the Mill Creek sections (in pocket).

All figured specimens are in the collections of the Geological Survey of Canada, Calgary, Alberta, and each specimen has a unique type number, ranging from GSC 114805 to 114973.

Anteturma SPORITES H. Potonié 1893

Turma TRILETES Reinsch 1881 emend. Dettmann 1963

Suprasubturma ACAVATITRILETES Dettmann 1963

Subturma AZONOTRILETES Luber 1935 emend. Dettmann 1963

Infraturma LAEVIGATI Bennie & Kidston 1886 emend. Potonié 1956

Genus *Biretisporites* Delcourt & Sprumont 1955 emend. Delcourt, Dettmann & Hughes 1963

18 *Biretisporites potoniaei* Delcourt & Sprumont 1955

Genus *Concavisporites* Pflug in Thomson & Pflug 1953 emend. Delcourt & Sprumont 1955

19 *Concavisporites jurienensis* Balme 1957

Genus *Concavissimisporites* Delcourt & Sprumont 1955 emend. Singh 1964

91 *Concavissimisporites parkinii* (Pocock, 1962) Singh 1964

Plate 1, figure 1

Remarks. A single specimen identified with other, probably reworked Early Cretaceous taxa in Lynx Creek strata. The thick walls (3 µm) are thought to enhance its preservation potential.

84 *Concavissimisporites punctatus* (Delcourt & Sprumont) Singh 1964

Genus *Cyathidites* Couper 1953

7 *Cyathidites minor* Couper 1953

Genus *Deltoidospora* Miner emend. Potonié 1956

28 *Deltoidospora diaphana* Wilson & Webster 1946

1 *Deltoidospora hallii* Miner 1935

Plate 1, figure 2

Remarks. *Deltoidospora hallii* is commonly found in all samples. Its wall structure is apparently impervious to a wide variety of chemical and physical processes of degradation.

20 *Deltoidospora psilostoma* Rouse 1959

Genus *Dictyophyllidites* Couper emend. Dettmann 1963

9 *Dictyophyllidites* sp.

Genus *Stereisporites* Pflug 1953

14 *Stereisporites antiquasporites* (Wilson & Webster) Dettmann 1963

Genus *Todisporites* Couper 1958

58 *Todisporites minor* Couper 1958

Genus *Undulatisporites* Pflug 1953

60 *Undulatisporites undulapolus* Brenner 1963

Infraturma APICULATI Bennie & Kidston emend. Potonié 1956

Genus *Baculatisporites* Thompson and Pflug 1953

45 *Baculatisporites comaumensis* (Cookson) Potonié 1956

Genus *Ceratosporites* Cookson and Dettmann 1958

11 *Ceratosporites pocockii* Srivastava 1972

Genus *Concavissimisporites* Delcourt & Sprumont emend. Singh 1964

61 *Concavissimisporites asper* (Bolkhovitina) Pocock 1962

21 *Concavissimisporites penolaensis* Dettmann 1963

Plate 1, figure 3

Remarks. When compared with *Concavissimisporites parkinii*, *C. penolaensis* is seen to be a relatively smaller spore with low verrucae and a 1.5 µm wall.

42 *Concavissimisporites variverrucatus* (Couper) Brenner 1963

Plate 1, figure 4

Remarks. Specimens are not common and tend to be degraded. Secure identifications are not always possible.

Genus *Foraminisporis* Krutzsch 1959

24 *Foraminisporis wonthaggiensis* (Cookson & Dettmann) Dettmann 1963

Genus *Granulatisporites* Ibrahim emend. Potonié & Kremp 1954

15 *Granulatisporites* sp.

Genus *Leptolepidites* Couper emend. Norris 1968

74 *Leptolepidites verrucatus* Couper 1953

79 *Leptolepidites* sp. cf. *L. irregularis* of Wingate 1980

Genus *Lophotriletes* Naumova ex. Potonié & Kremp 1954

23 *Lophotriletes babsae* (Brenner) Singh 1971

Plate 1, figure 5

Remarks. *Lophotriletes babsae* is broadly triangular in shape. Echinae are evenly distributed on both the proximal and distal surfaces.

Genus *Neoraistricka* Potonié 1956

98 *Neoraistrickia truncata* (Cookson) Potonié 1956

Genus *Osmundacidites* Couper 1953

33 *Osmundacidites wellmanii* Couper 1953

Genus *Ornamentifera echinata* Delcourt & Sprumont 1955

78 *Pilosisporites brevipapillosus* Couper 1958

Plate 1, figures 6, 7

1958 *Pilosisporites brevipapillosus* Couper, p. 144.
1971 Auct. non *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina, 1966 in Singh, p. 98.
1980 *Lophotriletes brevipapillosus* (Couper) Wingate, p. 27.

Remarks. Specimens identified from this study vary in an apparently random manner from those with or without an interradial crassitude. Singh (1971) classified specimens with an interradial crassitude as *Ornamentifera echinata*; these occur in Cadotte Member and younger strata from the Peace River area.

22 *Pilosisporites trichopapillosus* (Thiergart) Delcourt & Sprumont 1955

Plate 1, figure 8

Remarks. *Pilosisporites trichopapillosus* is relatively common in the variegated strata from the upper part of the Beaver Mines Formation. Elsewhere in the measured sections from Mill Creek and Carbondale River, it tends to be very rare.

Genus *Stoverisporites* Burger 1976

77 *Stoverisporites lunaris* (Cookson & Dettmann) Burger 1976

Plate 1, figure 9

Remarks. *Stoverisporites lunaris* is relatively common in strata from the upper part of the Beaver Mines Formation. Elsewhere in the section it is very rare.

Genus *Verrucosisporites* Ibrahim emend. Potonié & Kremp 1954

72 *Verrucosisporites rotundus* Singh 1964

Plate 1, figure 10

Remarks. *Verrucosisporites rotundus* is relatively common in strata from the upper part of the Beaver Mines Formation and the Lynx Creek Member of the Mill Creek Formation. Elsewhere in Alberta, Singh (1964) recorded *V. rotundus* in Lower Mannville strata; Burden (unpublished) has identified a small number of specimens from basal Colorado sands.

Infraturma MURORNATI Potonié & Kremp 1954

Genus *Cibotiidites* Ross 1949

99 *Cibotiidites robusta* (Brenner) n. comb.

Plate 1, figures 11, 12

1964 *Neoraistricka robusta* Brenner, p. 65, Pl. 19, fig. 2.

Remarks. The genus *Cibotiidites* contains spores with a valvate exine ornamented with a reticulum formed of broad muri ornamented with verrucae and baculae.

Bacula on *C. robusta* are 4 to 10 µm in diameter; on average, they are significantly larger, higher and more widely spaced than the low 5 to 8 µm verrucae on *C. arlii* Srivastava 1977. Specimens identified by Wingate (1980) as *N. robusta* are *C. robusta*. Specimens from Alberta occur in the Bruin Creek Member of the Mill Creek Formation (this study) and basal strata of the Bow Island Formation (Burden, unpublished). A late Middle Albian through middle Late Albian age is suggested from the present distribution pattern.

Genus *Cicatricosisporites* Potonié and Gelletich 1933

52 *Cicatricosisporites annulatus* Archangelsky & Gamerro 1966

8 *Cicatricosisporites australiensis* (Cookson) Potonié 1956

81 *Cicatricosisporites crassistriatus* Burger 1966

Plate 1, figure 13

Remarks. *C. crassistriatus* is more commonly identified in older Neocomian rocks. It is identified from one sample containing a variety of other typical Early Cretaceous spores; reworking is suspected.

100 *Cicatricosisporites* sp. cf. *C. crassiterminatus* Hedlund 1966

Plate 1, figures 14, 15

Remarks. The few specimens identified in this study are not well preserved; hence the tentative identification. Other reports from North America place this species in Cenomanian and younger strata (Singh, 1983). If independent confirmation of these identifications are made, the range of *C. crassiterminatus* will expand into late Middle Albian strata.

6 *Cicatricosisporites hallei* Delcourt & Sprumont 1955

3 *Cicatricosisporites hughesi* Dettmann 1963

102 *Cicatricosisporites imbricatus* (Markova) Singh 1971

26 *Cicatricosisporites minor* (Bolkhovitina) Pocock 1964

Plate 1, figure 16

Remarks. *C. minor* is relatively common in Neocomian through earliest Albian Lower Mannville strata (Burden 1982). Specimens are not commonly encountered in the younger strata examined here.

83 *Cicatricosisporites mohrioides* Delcourt & Sprumont 1955

97 *Cicatricosisporites patapscoensis* Brenner 1963

Plate 1, figure 17

Remarks. *C. patapscoensis*, easily identified from its very broad ribs, has been previously identified from pollen Subzone B of the Patapsco Formation of Maryland (Brenner, 1964).

57 *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963

73 *Cicatricosisporites subrotundus* Brenner 1963

40 *Cicatricosisporites venustus* Deák 1963

Genus *Costatoperforosporites* Deák 1962

39 *Costatoperforosporites foveolatus* Deák 1962

Genus *Foveotriletes* Potonié 1956

12 *Foveotriletes subtriangularis* Brenner 1963

Plate 1, figure 18

Remarks. Commonly observed in the top of the Beaver Mines Formation and the Lynx Creek Member of the Mill Creek Formation, *F. subtriangularis* is a distinctive part of the early Cretaceous flora of Western Canada.

Genus *Ischyosporites* Balme 1957

94 *Ischyosporites disjunctus* Singh 1971

Plate 1, figure 19

Remarks. Two specimens are identified from a paleosoil containing an impoverished assemblage of spores and pollen, and dominated by *Pilosisporites trichopapillosus*. Singh (1971) suggested *I. disjunctus* is a Middle and Late Albian species.

27 *Ischyosporites punctatus* Cookson & Dettmann 1958

Plate 1, figure 20

Remarks. Common in the top of the Beaver Mines Formation, the few specimens identified in the Lynx Creek Member of the Mill Creek Formation tend to be broken and corroded.

Genus *Klukisporites* Couper 1958

51 *Klukisporites areolatus* Singh 1971

76 *Klukisporites foveolatus* Pocock 1964

30 *Klukisporites granulatus* (Pocock) Burden & Hills 1989

54 *Klukisporites pseudoreticulatus* Couper 1958

Genus *Lycopodiacidites* Couper emend. Potonié 1956

48 *Lycopodiacidites canaliculatus* Singh 1971

Genus *Microreticulatisporites* Knox emend. Bharadwaj 1955

86 *Microreticulatisporites uniformis* Singh 1964

Plate 1, figure 21

Remarks. Reported from only one sample of the Lynx Creek Member, *M. uniformis* is thought to be reworked from older strata.

Genus *Retitriletes* van der Hammen emend. Döring, Krutzsch, Mai & Schulz, 1963

34 *Retitriletes austroclavatidites* (Cookson) Döring, Krutzsch, Mai & Schulz 1963

37 *Retitriletes clavatoides* (Cookson) Döring, Krutzsch, Mai & Schulz 1963

13 *Retitriletes crassimacerius* (Hedlund) Burden & Hills 1989

46 *Retitriletes singhii* Srivastava 1972

Genus *Saxetia* Srivastava 1975

64 *Saxetia kiamichicola* Srivastava 1975

Genus *Tappanispora* Srivastava 1972

49 *Tappanispora reticulata* (Singh) Srivastava 1975

44 *Tappanispora scurranda* (Norris) Srivastava 1975

Subturma ZONOTRILETES Waltz 1935

Infraturma AURICULATI Schopf emend. Dettmann 1963

Genus *Appendicisporites* Weyland & Krieger emend.

Burden & Hills 1989

38 *Appendicisporites cristatus* (Markova) Pocock 1964

Plate 1, figure 22

Remarks. *Appendicisporites cristatus* is but one species in a complex of morphologically similar taxa that include, among others: *A. matesovae*, *A. auritus* Agasie, 1969, and *A. insignis* (Markova) Chlonova, 1976. For species in this complex, the most significant diagnostic feature is the junction and suture created from ribs from adjacent interradial regions. Ribs meeting as pairs along each radial axis fuse to form multiple appendices, which collectively are comblike in appearance. *Appendicisporites cristatus* is thought to represent the most simple form and perhaps the earliest member of this complex. Spores of *A. cristatus* tend to be less than 60 µm in diameter and ornamented with 4 to 8 narrow ribs that fuse into a short comblike projection.

88 *Appendicisporites erdtmanii* Pocock 1964

67 *Appendicisporites matesovae* (Bolchovitina) Norris 1967

Plate 1, figures 23, 24

Remarks. *Appendicisporites matesovae*, at 52 to 81 µm (*fide* Norris, 1967), tends to be slightly larger than *A. cristatus*. At 2 to 4 µm wide, the ribs on *A. matesovae* tend to be wider than those on *A. cristatus*. This contributes to the overall rounded appearance of this spore and its random equatorial and subpolar orientations. This species first appears in North America in the Middle Albian (Burden and Hills, 1989).

17 *Appendicisporites potomacensis* Brenner 1963

16 *Appendicisporites problematicus* (Burger) Singh 1971

95 *Appendicisporites spinosus* Pocock 1964

Plate 2, figure 1

Remarks. *Appendicisporites spinosus* is a part of a distinctive complex of species characterized by conate and echinate ornament projecting from the ribs and appendices. Not commonly reported, this species first appears in upper Mannville and equivalent strata of Western Canada.

59 *Appendicisporites tricostatus* (Bolchovitina) Pocock 1964

Plate 2, figure 2

Remarks. A very rare spore most often found in a broken and corroded state. It may be reworked from older strata.

43 *Appendicisporites unicus* (Markova) Singh 1964

Plate 2, figure 3

Remarks. Two assemblages of this species may be present. From sample scans and counts, the Beaver Mines Formation contain *A. unicus*, which has relatively short processes. In contrast, samples from higher in the section contain *A. unicus*, which has a higher number of spores with longer processes. Specimens from the Bow Island Formation are almost always those with the relatively longer processes (Burden, unpublished).

Genus *Impardecispora* Venkatachala, Kar & Raza 1968

66 *Impardecispora apiverrucata* (Couper) Venkatachala, Kar & Raza 1968

41 *Impardecispora crassa* (Brenner) Burden & Hills 1989

36 *Impardecispora marylandensis* (Brenner) Srivastava 1975

Plate 2, figure 4

Remarks. *Impardecispora marylandensis* is common throughout the Early Cretaceous of North America.

56 *Impardecispora minor* (Pocock) Venkatachala, Kar & Raza 1968

92 *Impardecispora tribotrys* (Dettmann) Venkatachala, Kar & Raza 1968

Genus *Plicatella* Malyavkina emend. Burden & Hills 1989

5 *Plicatella crimenensis* (Bolchovitina) Dörhöfer 1977

Remarks. Reported as a single observation from the Beaver Mines Formation, *P. crimenensis* is more commonly observed in lower Mannville strata of Western Canada.

Infraturma TRICRASSATI Dettmann 1963

Genus *Camarozonotriletes* Pant emend. Klaus 1960

101 *Camarozonotriletes ambigens* (Frankina) Playford 1971

Plate 2, figures 5–7

Remarks. This genus has distinctive interradial crassitudes, which separate it from *Lycopodiacidites* Couper, 1953 emend Potonić, 1956. *Camarozonosporites ambigens* may be a significant species for biostratigraphy. Inasmuch as sporadic and perhaps questionable observations are reported from older rocks (including a single broken specimen from the Lynx Creek Member of the Mill Creek Formation), *C. ambigens* is relatively common and abundant in Upper Albian strata throughout North America. This includes the Viking Formation of the Peace River Formation of Alberta (Norris, 1967), the upper Cadotte and Paddy members of Alberta (Singh, 1971), the Swan River Formation of Manitoba (Playford, 1971), and the Bow Island Formation (Burden, unpublished).

Genus *Foveogleicheniidites* Burger 1976

96 *Foveogleicheniidites confossus* (Hedlund) Burger 1976

Remarks. A secure identification is not always possible for the specimens identified from this study. Pitting may be the result of corrosion.

Genus *Gleicheniidites* Ross emend. Dettmann 1963

50 *Gleicheniidites bolchovitinae* Döring 1965

4 *Gleicheniidites circiniidites* (Cookson) Dettmann 1963

2 *Gleicheniidites senonicus* Ross 1949

Genus *Ornamentifera* Bolchovitina 1966

63 *Ornamentifera baculata* Singh 1971

Genus *Scopusporis* Wingate 1980

75 *Scopusporis spackmani* (Brenner) Wingate 1980

Plate 2, figure 8

Remarks. Brenner (1963) reported that this species is restricted to and common in subzone 2B of the Patapsco Formation of Maryland; Wingate (1980) reported rare specimens from the Denton Shale Member of Oklahoma. Though not commonly observed, this distinctive species is found in outcrops of the Mill Creek Formation and in the basal strata of the Bow Island Formation farther east in southern Alberta (Burden, unpublished). *Scopusporis spackmani* may be a useful biostratigraphic marker for regional correlation.

Genus *Sestrosporites* Dettmann 1963

89 *Sestrosporites pseudoalveolatus* (Couper) Dettmann 1963

Infraturma CINGULATI Potonié & Klaus emend. Dettmann 1963

Genus *Contignisporites* Dettmann 1963

85 *Contignisporites glebulentus* Dettmann 1963

Plate 2, figure 9

Remarks. The single specimen reported from this study may be derived from long-distance transport, an uncommon plant in the nearby vegetation or, more likely, reworking of older strata. Other fossils observed in the sample containing *C. glebulentus* are typically found in older Neocomian strata.

Genus *Distaltriangulisporites* Singh 1971

90 *Distaltriangulisporites irregularis* Singh 1971

62 *Distaltriangulisporites mutabilis* Singh 1971

Plate 2, figure 10

Remarks. Though not commonly observed, *Distaltriangulisporites mutabilis* is widely distributed in Aptian and Albian strata of Western Canada.

35 *Distaltriangulisporites perplexus* (Singh) Singh 1971

Genus *Interulobites* Paden Phillips & Felix 1971

87 *Interulobites intraverrucatus* (Brenner) Paden Phillips & Felix 1971

Plate 2, figure 11

Remarks. Typically identified from Aptian and Albian strata, *I. intraverrucatus* is, in this study, confined to a small number of samples of Mill Creek strata.

70 *Interulobites triangularis* (Brenner) Paden Phillips & Felix 1971

Genus *Kraeuselisporites* Leschik emend. Jansonius 1962

69 *Kraeuselisporites hastilobatus* Playford 1971

Genus *Polycingulatisporites* Simoncsics & Kedves emend. Burden & Hills 1989

53 *Polycingulatisporites reduncus* (Bolkhovitina) Playford & Dettmann 1965

71 *Polycingulatisporites* sp. cf. *P. radiatus* Singh 1971

Genus *Taurocusporites* Stover 1962

82 *Taurocusporites segmentatus* Stover 1962

Plate 2, figure 12

Remarks. The single specimen reported from this study is thought to be derived from reworking of older strata. Other fossils observed in the sample include spores typically found in Neocomian rocks and much older Paleozoic spores and pollen.

Turma MONOLETES Ibrahim 1933

Suprasubturma ACAVATOMONOLETES Dettmann 1963

Subturma AZONOMONOLETES Luber 1935

Infraturma LAEVIGATOMONOLETI Dybová & Jachowicz 1957

Genus *Laevigatosporites* Ibrahim emend. Schopf, Wilson & Bentall 1944

10 *Laevigatosporites ovatus* Wilson & Webster 1946

Plate 2, figure 13

Remarks. A long-ranging taxon, *L. ovatus* and other smooth-walled spores, are abundant in oxidized samples of paleosoil.

Infraturma SCULPTATOMONOLETI Dybová & Jachowicz 1957

Genus *Cicatricososporites* Thomson & Pflug ex. Krutzsch 1959

68 *Cicatricososporites phaseolus* (Delcourt & Sprumont) Krutzsch 1959

Suprasubturma PERINOMONOLETES Erdtman 1947

Genus *Peromonoletes* Erdtman ex. Couper 1953

55 *Peromonoletes allensis* Brenner 1963

Turma HILATES Dettmann 1963

Suprasubturma CAVATIHILATES Smith & Butterworth 1967

Subturma ZONOCAVATIHILATES Smith & Butterworth 1967

Genus *Triporoletes* Mtchedlishvili emend. Playford 1971

29 *Triporoletes radiatus* (Dettmann) Playford 1971

Plate 2, figure 14

Remarks. *Triporoletes radiatus* is confined to a small number of samples from the top of the Beaver Mines Formation and the basal rocks of the Lynx Creek Member of the Mill Creek Formation. It may have potential for local biostratigraphy or regional paleoenvironment studies.

25 *Triporoletes reticulatus* (Pocock) Playford 1971

Plate 2, figure 15

Remarks. *Triporoletes reticulatus* has a prominent distal reticulum of wide lumina and low muri. It is easily distinguished from *T. radiatus*, which has low muri that radiate from the distal polar area to form incomplete lumina. The distribution pattern for *T. reticulatus* is the same as that described for *T. radiatus*.

93 *Triporoletes singularis* Mtchedlishvili 1960

Suprasubturma ACAVATIHILATES Smith & Butterworth 1967

Genus *Aequitriradites* Delcourt & Sprumont emend. Cookson & Dettmann 1961

65 *Aequitriradites variabilis* Pocock 1962

Plate 2, figure 16

Remarks. Burden and Hills (1989) suggested that *A. variabilis* disappears in the Middle Albian.

32 *Aequitriradites verrucosus* (Cookson & Dettmann)

Cookson & Dettmann 1961

Plate 2, figure 17

Remarks. The surface ornament for *A. verrucosus* is distinctively reticulate. The results for this study show both *A. variabilis* and *A. verrucosus* are confined to the upper part of the upper Beaver Mines Formation at the Carbondale River section.

Genus *Couperisporites* Pocock 1962

31 *Couperisporites complexus* (Couper) Pocock 1962

Plate 2, figure 18

Remarks. *Couperisporites complexus* occurs in a single sample from the upper part of the Beaver Mines Formation on the Carbondale River. Burden and Hills (1989) suggested that *C. complexus* disappears in the Middle Albian.

Genus *Januasporites* Pocock 1962

47 *Januasporites spiniferus* Singh 1964

Plate 2, figure 19

Remarks. *Januasporites spiniferus* is confined to a small number of samples from the top of the Beaver Mines Formation and the basal rocks of the Lynx Creek Member of the Mill Creek Formation. Farther east in the subsurface, *J. spiniferus* occurs in the basal Colorado sand and in the directly overlying Bow Island Formation (Burden, unpublished). Burden and Hills (1989) suggested that this species disappears in the Middle Albian. It may have potential for local biostratigraphy or regional paleo-environment studies.

Anteturma POLLENITES Potonié 1931

Turma SACCITES Erdtman 1947

Subturma MONOSACCITES Chitaley emend. Potonié & Kremp 1954

Infraturma SACCIZONATI Bhardwaj 1957

Genus *Callialasporites* Dev 1961

80 *Callialasporites dampieri* (Balme) Dev 1961

Genus *Cerebropollenites* Nilsson 1958

111 *Cerebropollenites mesozoicus* (Couper) Nilsson 1958

Subturma DISACCITES Cookson 1947

Infraturma DISACCIASTRILETI Leschik emend. Potonié 1958

Genus *Alisporites* Daugherty emend. Jansonius 1971

113 *Alisporites bilateralis* Rouse 1959

Plate 3, figures 1, 2

Remarks. *Alisporites bilateralis* is common to abundant in nearly all samples examined in this study.

122 *Alisporites grandis* (Cookson) Dettmann 1963

Genus *Cedripites* Wodehouse 1933

115 *Cedripites canadensis* Pocock 1962

123 *Cedripites cretaceus* Pocock 1962

Genus *Pityosporites* Seward emend. Manum 1960

106 *Pityosporites alatipollenites* (Rouse) Singh 1964

114 *Pityosporites constrictus* Singh 1964

Genus *Podocarpidites* Cookson ex. Couper 1953

116 *Podocarpidites biformis* Rouse 1957

118 *Podocarpidites canadensis* Pocock 1962

119 *Podocarpidites granulatus* Singh 1971

105 *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962

117 *Podocarpidites minisculus* Singh 1964

Genus *Pristinuspollenites* Tschudy 1973

110 *Pristinuspollenites* sp.

Genus *Rugubivesiculites* Pierce 1961

124 *Rugubivesiculites rugosus* Pierce 1961

Plate 3, figure 3

Remarks. *Rugubivesiculites rugosus* occurs in Blackstone Formation strata lying unconformably above the Crowsnest Volcanics. Elsewhere in Alberta, *R. rugosus* is identified from the Viking Formation and upper shale unit of the lower part of the Colorado Group of central Alberta (Norris, 1967), which is now called the Westgate Formation (Bloch et al., 1993), the lower Shaftesbury Formation of the Peace River area (Singh, 1971), middle and upper Bow Island Formation, and lower Colorado shale of southern Alberta (Burden, unpublished). *Rugubivesiculites rugosus* may be a significant marker for regional biostratigraphy.

Genus *Vitreisporites* Leschik emend. Jansonius 1962

104 *Vitreisporites pallidus* (Reissinger) Nilsson 1958

Plate 3, figure 4

Remarks. *Vitreisporites pallidus* is a secondary component identified in small numbers in nearly all samples examined in this study.

Turma ALETES Ibrahim 1933

Subturma AZONOLETES Luber emend. Potonié & Kremp 1954

Infraturma PSILONAPITI Erdtman 1947

Genus *Inaperturopollenites* Pflug & Thompson emend. Potonié 1958

103 *Inaperturopollenites* sp.

Genus *Taxodiaceaepollenites* Kremp ex. Potonié 1958

103 *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1950

Infraturma GRANULONAPITI Cookson 1947

Genus *Araucariacites* Cookson ex. Couper 1953

120 *Araucariacites australis* Cookson 1947

Turma POROSES Naumova emend. Potonié 1960

Subturma MONOPORINES Naumova 1939

Genus *Circulina* Malyavkina emend. Cornet & Traverse 1975

108 *Circulina parva* Brenner 1963

Genus *Classopollis* Pflug emend. Pocock & Jansonius 1961

112 *Classopollis* sp.

Remarks. Though widely distributed, specimens of *Classopollis* were not commonly identified in the samples examined in this study. Species identifications were not attempted.

Turma PLICATES Naumova emend. Potonié 1960

Subturma COSTATES Potonié 1970

Infraturma COSTATI Jansonius 1962

Genus *Equisetosporites* Daugherty emend. Singh 1964

121 *Equisetosporites* sp. cf. *E. pentacostatus* (Brenner) Wingate 1980

Subturma MONOCOLPATES Iversen & Troels-Smith 1950

Infraturma QUASILEVIGATI Potonié 1970

Genus *Cycadopites* Wodehouse ex. Wilson & Webster 1946

107 *Cycadopites* sp.

Infraturma SCULPTATI Potonié 1970

Genus *Clavatipollenites* Couper 1958

152 *Clavatipollenites hughesii* Couper 1958

Plate 3, figures 5, 6

Remarks. The length times width measurements for three specimens varied from 22–24 x 16–21 µm. Pila arranged as a microreticulum are about 0.75 µm high; the endexine is about 0.25 µm thick. When visible, the margin of the sulcus

is usually well developed with straight edges. Burden (1984) suggested that *C. hughesii* appears in Alberta in the early Barremian.

160 *Clavatipollenites minutus* Brenner 1963

Plate 3, figure 7

Remarks. Two measured specimens of *C. minutus* are 15 and 17 µm in diameter and nearly circular in outline. The exine tends to be less than 0.75 µm thick with pila no more than 0.5 µm high and arranged as a microreticulum. The sulcus margin is irregular in outline giving the grain a ragged appearance. The small size and circular outline distinguish *C. minutus* from other species of this genus.

133 *Clavatipollenites tenellis* Paden Phillips & Felix 1971

Plate 3, figures 8, 9

Remarks. As with *C. minutus*, *C. tenellis* tends to be circular in outline but much larger in size (24–27 µm diameter; 3 specimens measured). The wall, up to 1.5 µm thick, contains pila up to 0.5 µm high. Pila form a microreticulum with muri no more than 0.3 µm wide and lumina less than 1 µm wide. When visible, the sulcus is a thickened, smooth membrane with irregular margins. The sulcus is commonly removed to leave a ragged outline. *C. tenellis* is distinguished from *C. hughesii*, which has an elliptical outline and straight, sharply defined sulcus margin.

Genus *Liliacidites* Couper 1953

161 *Liliacidites doylei* Ward 1986

Plate 3, figures 10, 11

Remarks. Two specimens were identified from the Mill Creek Formation. The grain from the Bruin Creek Member (Plate 3, fig. 11) is elliptical in polar view and 30 x 18 µm in size. A larger grain, apparently belonging to the same species, occurs in the Carbondale Member; it is 37 x 20 µm in size (Plate 3, fig. 10). Muri in the mesocolpal area of the smaller grain are 0.4 µm high and about 0.3 µm wide; in the larger grain, the muri are 0.7 µm wide and 0.7 µm high. The endexine is 0.3 µm thick in both specimens. Muri form a polygonal reticulum with lumina 1.5 µm diameter in the mesocolpal area of the small grain and 2.5 µm in the larger grain. An area extending about 6 µm from each pole is psilate to punctate in texture. *L. doylei* occurs in the Kiowa Formation of Kansas and the Patapsco Formation of Maryland and Delaware (Ward 1986); current distribution patterns suggest a middle Middle Albian through early Cenomanian age.

163 *Liliacidites inaequalis* Singh 1971

Plate 3, figures 12, 13

Remarks. The length times width measurements for two specimens are 38 x 22 µm and 37 x 15 µm. The poles tend to be rounded. Muri in the mesocolpal area are 1.5 µm high and about 1.0 µm wide, decreasing to about 0.5 µm wide and 0.5 µm high at the poles. The endexine is 0.3 µm thick. Muri form a polygonal reticulum with lumina 3.0 to 4.0 µm in diameter in the mesocolpal area; in contrast, lumina in a field extending 6 µm from the poles are less than 1.0 µm in diameter. *L. inaequalis* occurs in the Cheyenne and Kiowa formations of Kansas (Ward 1986), Patapsco Formation of Maryland and Delaware (Doyle and Robbins 1977), and the Paddy, Shaftesbury, and Dunvegan formations of Alberta (Singh, 1971, 1983). Current distribution patterns suggest a middle Middle Albian through early Cenomanian age.

167 *Liliacidites tectatus* Singh 1983

Plate 3, figure 14

Remarks. A single specimen, measuring 27 µm in diameter, comes from the Bruin Creek Member. Lumina are about 1.5 µm around the periphery of the grain, decreasing to less than 1.0 µm at the edge of a 12 µm tectate area. The sulcus is not clear.

137 *Liliacidites* sp. D of Doyle and Robbins 1977

Plate 3, figure 15

Remarks. One corroded grain measuring 62 x 30 µm is identified from the top of the Beaver Mines Formation. Muri about 0.25 µm wide form lumina 5–7 µm in diameter in the mesocopal area. In contrast, an area extending about 6 µm from the poles contains a reticulum with lumina less than 1.0 µm in diameter.

159 *Liliacidites* sp. E of Doyle and Robbins 1977

Plate 3, figure 16

Remarks. *Liliacidites* sp. E is an uncommon yet widely distributed taxon in the study area. Two measured specimens are elliptical in shape and 22 x 16 µm in outline. Muri about 0.3 µm wide and 0.5 µm high form a reticulum that decreases in a uniform manner from about 1.0 µm in the mesocopal area to about 0.5 µm at the poles. The sulcus is bordered by pits or small lumina. Doyle and Robbins (1977) suggested that the range of this species is middle Middle Albian to Cenomanian.

136 *Liliacidites* sp.

Plate 3, figure 17

Remarks. A single specimen measuring about 50 x 18 µm in outline is identified from the top of the Beaver Mines Formation. Muri about 0.5 µm wide and 1.3 µm high form a reticulum about 2.5 µm in diameter. The sulcus, not clearly illustrated, apparently extends the full length of the grain. Muri surrounding the sulcus are about 1.0 µm diameter.

Genus *Racemonocolpites* Guzmán 1967

142 *Racemonocolpites* sp.

Plate 3, figures 18–20

Remarks. Monosulcate pollen with robust gemma, bacula and clava 1–1.5 µm wide and 1.5–2.0 µm high are included here. Three specimens that vary widely in overall dimensions and ornament (32–55 µm x 27–40 µm) suggest more than one species.

Genus *Retimonocolpites* Pierce 1961

147 *Retimonocolpites crassatus* (Singh) Singh 1983

Plate 3, figures 21–23

Remarks. Three measured grains are nearly circular in outline and 16–20 µm in diameter. The wall, about 1.0 µm thick, consists of a smooth, solid endexine about 0.3 µm thick and a clavate tectum 0.7 µm high. Clavae join to form muri about 0.5 µm wide and polygonal lumina about 1.0 µm in diameter. The grains are slightly smaller than but otherwise identical to the diagnosis provided by Singh (1971). Burden and Hills (1989) suggested that *R. crassatus* appeared in Alberta in the early Barremian.

146 *Retimonocolpites dividuus* Pierce 1961

Plate 4, figures 1, 2

Remarks. Two measured and illustrated specimens are thought to represent the significant characteristics of this species. Specimens are round or subrounded in outline and 20–27 µm in diameter. The surface is microreticulate with lumina about 1.0 µm or less in diameter. The sulcus has a distinctive, characteristically thickened margin about 2.0 µm wide. The fine reticulum and thickened margin on the sulcus distinguish *R. dividuus* from other species of the genus.

172 *Retimonocolpites peroreticulatus* (Brenner) Doyle, van Campo & Lugardon 1975

Plate 4, figures 3–6

Remarks. *R. peroreticulatus* is a relatively small, elliptical grain (12–17 x 10–14 µm; 5 specimens measured) with a high, loose-fitting, coarse reticulum of narrow muri (0.3 µm wide) and wide lumina (3–5 µm diameter). Most of the specimens have smooth muri; a few specimens observed from the Bruin Creek Member have muri that are beaded in appearance (Pl. 4, fig. 5, 6).

153 *Retimonocolpites reticulatus* (Brenner) Doyle, van Campo & Lugardon 1975

Plate 4, figure 7

Remarks. *R. reticulatus* (15–20 x 10–16 µm; 4 specimens) is similar in size and shape to *R. peroreticulatus*. The lumina are smaller, about 1.0–1.5 µm in diameter and about 1.0 µm high. Burden and Hills (1989) suggested that *R. reticulatus* first appears in Alberta in the Aptian.

145 *Retimonocolpites textus* (Norris) Singh 1983

Plate 4, figures 8, 9

Remarks. Specimens of *R. textus* vary from 21–23 x 13–16 µm in outline, tending to be slightly larger and more elongated than *R. reticulatus*. Both species have a degree of overlap with one another and separation is not always easy. For this study, specimens assignable to *R. textus* are not seen to extend into the Beaver Mines Formation. Specimens from the Lynx Creek Member appear smaller than the specimens described by Norris (1967); larger specimens, matching *R. textus* in both size and length-to-breadth ratio, occur only in the Bruin Creek Member.

Subturma TRI(POLY)CHOTOMOSULCATES Erdtman 1945

Infraturma EUTRICHOTOMOSULCATI Potonié 1975

Genus *Asteropollis* Hedlund & Norris 1968

149 *Asteropollis asteroides* Hedlund & Norris 1968

Plate 4, figure 10

Remarks. Grains tend to be round in outline and 24–26 µm diameter (3 measured). The wall is about 1.0 µm thick and contains pila about 0.5 µm high. Pila are arranged as a microreticulum with lumina less than 1.0 µm in diameter. The sulcus contains four or five branches that appear as a star-like pattern.

154 *Asteropollis trichotomosulcatus* (Singh) Singh 1983

Plate 4, figures 11, 12

Remarks. Two specimens 22 and 26 µm in diameter apparently have a three-branched sulcus conforming with Singh's description for *A. trichotomosulcatus*. Ward (1986) considered *A. trichotomosulcatus* a junior synonym for *A. asteroides*.

Subturma TRIPTYCHES Naumova 1939

Infraturma PRAECOLPATI Potonié & Kremp 1954

Genus *Eucommidites* Erdtman emend. Hughes 1961

109 *Eucommidites* sp.

Infraturma ISOTRICOLPATI Potonié 1970

Genus *Cupuliferoidaepollenites* Potonié, Thomson & Thiergart 1950

165 *Cupuliferoidaepollenites parvulus* (Groot & Penny) Dettmann 1973

Plate 4, figures 13, 14

Remarks. Small (12–14 µm equatorial outline; 2 specimens), psilate, tricolpate pollen not easily confused with other taxa. Doyle and Robbins (1977) suggested that *C. parvulus* appears in the Early Albian.

Genus *Foveotricolpites* Pierce 1961

150 *Foveotricolpites concinnus* Singh 1971

Plate 4, figures 15, 16

Remarks. Three measured specimens of *F. concinnus* are elliptical in polar outline (27–30 x 20–22 µm; 2 specimens) and circular in equatorial outline (22 µm; 1 specimen). The 1.5–2.0 µm thick wall contains robust collumellae up to 0.5 µm in diameter and more than 1.0 µm long. Fovea 1–2 µm in diameter are evenly spaced and of uniform size. *F. concinnus* is larger than *Tricolpites fragosus* (Hedlund and Norris) Ward 1986 (12–18 x 10–18 µm *fide* Ward). The evenly distributed and uniform dimensions for the fovea easily distinguish *F. concinnus* from smaller specimens of *Rousea brenneri* Singh 1983. Burden and Hills (1989) suggested that *F. concinnus* first appears in the Early Albian.

Genus *Phimopollenites* Dettmann 1973

170 *Phimopollenites augathellaensis* (Burger) Dettmann 1973

Plate 4, figures 17, 18

Remarks. Dettmann (1973) established *Phimopollenites* for foveolate to finely reticulate fossil pollen with irregular colpoid margins (tricolpoidate). Two measured specimens from the Bruin Creek Member are 22 and 24 µm in equatorial outline. The reticulum consists of muri about 0.3 µm wide and lumina about 1.0 µm in diameter. The wall, less than 1.0 µm thick, is columellate with pila about 0.5 µm high. *P. pseudocheros* Srivastava 1975 may be a junior synonym.

171 *Phimopollenites pannosus* (Dettmann & Playford) Dettmann 1973

Plate 4, figures 19, 20

Remarks. *P. pannosus* (16 and 17 µm equatorial outline; 2 specimens) is similar to but smaller than *P. augathellaensis*. The wall, about 1.0 µm thick, is columellate with pila about 0.5 µm high. Previous records suggest that *P. pannosus* appears in North America in the Middle Albian (Ward, 1986).

Genus *Retitrescolpites* Sah 1967

173 *Retitrescolpites kempiae* Ward 1986

Plate 4, figure 21

Remarks. The two specimens identified in this study have muri that are about 1.0 µm high and 0.5 µm wide; lumina are 1–2 µm in diameter and show no appreciable change in size over the grain surface. In polar outline one grain is 18 x 12 µm in size; the second grain is apparently larger, with an equatorial outline of 27 µm in diameter, and slightly larger dimensions than those indicated by Ward (1986).

The muri tend to be higher than those for *R. virgeus* (Groot, Penny and Groot) n. comb., giving the reticulum a shaggy, loose fitting appearance. Ward (1986) reported this species occuring in Middle Albian through middle Cenomanian strata of Europe and North America.

138 *Retitrescolpites maximus* (Singh) n. comb.

Plate 4, figures 22, 23

1971 *Retitricolpites maximus* Singh, p. 201, Pl. 30, fig. 7–9; Pl. 31, fig. 1, 2.

1986 *Tricolpites maximus* (Singh) Ward, p. 56, Pl. 15, fig. 8–11.

Remarks. *R. maximus* was erected by Singh to accommodate relatively large grains with uniformly distributed lumina greater than 1 µm. Superficially resembling *R. virgeus* (22–30 x 16–22 µm; *fide* Singh, 1971), *R. maximus* tends to be significantly larger (27–45 x 20–36 µm; *fide* Ward, 1986). In addition, the lumina for *R. maximus* tend to be incomplete, forming an imperfect reticulum of vermiculate muri that end with clavae.

The equatorial diameter for two complete specimens is 30 and 38 µm. Another, larger, broken specimen is apparently quadricolpate.

140 *Retitrescolpites vermimurus* (Brenner) n. comb.

Plate 4, figures 24–26

1958 *Retitricolpites vermimurus* Brenner, p. 92, Pl. 39, fig. 2, 3.
1977a *Striatopollis vermimurus* (Brenner) Srivastava, p. 97, (err. orth. pro *vermimura*).

Remarks. *Retitrescolpites* Sah 1967 was created to circumscribe retipilate–retipilariate–reticulate tricolpate pollen with usually sinuous muri (Jansonius and Hills 1976). *Striatopollis* Krutzsch 1959 was originally instituted for striate pollen. Later, Singh (1971) and Dettmann (1973) enlarged the diagnosis to include striato-reticulate ornament. In concurrence with Ward's suggestion, the diagnosis for *Striatopollis* should be taken *sensu stricto*; striato-reticulate species are removed. *R. vermimurus* is reticulate with elongate lumina up to 2.5 x 4.0 µm delineated by sinuous muri 0.5 µm wide and 1.0 µm high.

141 *Retitrescolpites virgeus* (Groot, Penny & Groot) n. comb.

Plate 4, figures 27–29

1961 *Tricolpopollenites virgeus* Groot, Penny and Groot, p. 133, Pl. 26, fig. 16, 17.
1963 *Retitricolpites virgeus* (Groot, Penny and Groot) Brenner, p. 92, Pl. 39, fig. 4, 5.

Remarks. Singh's description and illustrations clearly show a tight fitting reticulum with lumina 1.5–3.0 µm in diameter; these are clearly larger than lumina described for *Tricolpites cooksonae* Dettmann. Muri on *R. virgeus* are structurally different from *R. kempiae*. Muri on *R. virgeus* contain bacula that may project above the tegillum; the surface for muri on *R. kempiae* is smooth, with fewer rods holding the reticulum in place. It remains to be seen whether the specimens identified here and those described by Singh (1971) remain in this species; Dettmann (1973) noted the type material for *R. virgeus* is larger.

Genus *Rousea* Srivastava 1969

156 *Rousea brenneri* Singh 1983

Plate 5, figures 1–6

Remarks. Two relatively well preserved specimens measure 49–52 x 23–30 µm. Three other broken specimens suggest that the polar axis may get to be as much as 60 µm long with an equatorial diameter of more than 50 µm. These measurements are consistent with, though slightly larger than dimensions (43–49 x 24–43 µm) presented by Singh (1983). Muri are about 1 µm wide and up to 1.5 µm high in the mesocolpal region, 0.75 µm wide and 0.75 µm high at the poles. They have a beaded appearance, which is particularly evident in transmitted light. Lumina decrease in size from 2–3 µm in the mesocolpal area to about 0.50 µm at the poles. The larger size and more robust features distinguish this species from others of the genus.

135 *Rousea georgensis* (Brenner) Dettmann 1973

Plate 5, figures 7–10

Remarks. The equatorial axis for three grains is 16–21 µm; one grain shows a polar axis of 29 µm. All specimens have lumina that vary from 1.5 µm in the equatorial region to 0.25 µm at the poles. Muri are about 0.25 µm wide and 0.50 µm high. The total thickness of the wall is about 0.75 µm.

174 *Rousea marthae* Ward 1986

Plate 5, figures 11, 12

Remarks. *R. marthae* is distinguished from other species of *Rousea* by tiny lumina (0.25 µm diameter) scattered between larger lumina (2 µm diameter) and on the colp margins. Two specimens are 20–21 x 12–13 µm in equatorial view. A cluster of five pollen grains belonging to this species was also identified from the Bruin Creek Member. Individual grains in this cluster are 11 µm in diameter.

164 *Rousea miculipollis* Srivastava 1975

Plate 5, figure 13

Remarks. One specimen was identified from the Lynx Creek Member. This prolate grain is 21 x 13 µm in size. It is distinguished from other species by its relatively large lumina (3 µm in diameter), which decrease to 0.5 µm diameter at the poles. Muri, 0.5 µm wide and 0.75 µm high, are composed of closely spaced pila. The wall is 1.5 µm

thick. The reported distribution pattern for this species suggests it is an Upper Albian fossil (Ward, 1986).

144 *Rousea prosimilis* (Norris) Srivastava 1975

Plate 5, figures 14–16

Remarks. Specimens identified here as *R. prosimilis* tend to have smaller lumina (maximum diameter 1.25 µm) than *R. georgensis*. *R. prosimilis* may be distinguished with some difficulty from *Tricolpites micromunus*, which has an evenly distributed reticulum. Five specimens measured for this study vary from 16–26 x 12–19 µm. The wall is about 0.75 µm thick.

Genus *Striatopollis* Krutzsch 1959

169 *Striatopollis paranea* (Norris) Singh 1971

Plate 5, figures 17, 18

Remarks. Two prolate grains about 20 x 10 µm in size and conforming with Norris's (1967) description were found in the Bruin Creek Member. The reticulum in the equatorial region contains lumina about 0.75 µm diameter; these pass into striate muri 0.5 µm wide and 0.25 µm high about 4 µm from the poles. The combination of striations in the polar regions with a reticulum at the equator are very characteristic; Ward (1986) suggested that another generic diagnosis may be needed for these forms. Doyle and Robbins (1977) separated this species from other striate pollen; *S. paranea s.s.* first appears in rocks likely to be early Late Albian in age.

168 *Striatopollis* sp.

Plate 5, figures 19, 20

Remarks. Prolate pollen with a striate pattern covering the exine surface. Muri are very low and narrow, giving the grain an almost psilate appearance. Grain dimensions for four specimens vary from 12–16 x 8–11 µm. The wall is about 0.5 µm thick. Grains from the Cadotte Member of the Peace River Formation illustrated by Singh (1971) as *S. paranea* are probably *Striatopollis* sp. Doyle and Robbins (1977) recorded a similar form, *Striatopollis* sp. A, which appears in Middle Albian to early Late Albian strata and before *S. paranea*.

Genus *Tricolpites* Cookson emend. Potonié 1960

143 *Tricolpites crassimurus* (Groot & Penny) Singh 1971

Plate 5, figures 21–23

Remarks. Three specimens vary in size from 36–48 µm in equatorial diameter. *T. crassimurus* is distinguished from other species of the genus by its relatively large size, thin walls (0.75 µm), and scabrate surface texture.

166 *Tricolpites fragosus* (Hedlund & Norris) Ward 1986

Plate 6, figures 1, 2

Remarks. Two measured specimens are preserved in polar view; their equatorial axes are 16 and 17 µm. Fovea 0.25–0.50 µm in diameter are separated by muri 0.5–1.0 µm. The endexine is about 1.0 µm and the entire wall about 1.5 µm thick. Colps do not extend to the poles and the polar area is relatively large.

134 *Tricolpites micromunus* (Groot & Penny) Singh 1971

Plate 6, figures 3–5

Remarks. *T. micromunus* is perhaps the most common angiosperm in the assemblages identified here; it is also one of the more difficult forms to recognize. Its subprolate to prolate shape and relatively small size (15–19 x 10–18 µm; 5 specimens) may be confused with small *T. parvus* or large *T. minutus*. The ornament, consisting of lumina about 0.25 µm in diameter separated by muri that are also 0.25 µm wide, may, on poorly preserved specimens, resemble the graded lumina on *Rousea prosimilis*. The wall is about 0.75 µm thick.

157 *Tricolpites minutus* (Brenner) Dettmann 1973

Remarks. Recent workers (Ward, 1986) tend to arbitrarily identify finely reticulate grains on the basis of a short polar axis, 13 µm long. Small specimens, otherwise referable to *T. micromunus*, and having a polar axis of 13 µm or less, are identified as *T. minutus*. It remains to be seen whether this rather arbitrary diagnosis stands.

151 *Tricolpites parvus* Stanley 1965

Plate 6, figures 6, 7

Remarks. *T. parvus* identified here are characterized by uniformly small lumina less than 0.5 µm in diameter and muri 0.25 µm wide; the wall is about 0.75 µm thick. In equatorial outline the species ranges from 24–30 µm in diameter (4 specimens); polar diameter (1 specimen) is 30 µm. *T. parvus* is significantly larger than either *T. minutus* (10–13 x 6–10 µm; *fide* Brenner, 1963) or *T. micromunus* (12–19 x 10–15 µm; *fide* Brenner, 1963).

158 *Tricolpites sagax* Norris 1967

Plate 6, figures 8, 9

Remarks. Ornamentation on *T. sagax* appears as small scabrae projecting above a relatively thick (1.5 µm), microreticulate wall. Three specimens measured for this study are nearly circular in outline and 18 µm in diameter; a fourth specimen is 24 µm in diameter.

148 *Tricolpites vulgaris* (Pierce) Srivastava 1969

Plate 6, figures 10–13

Remarks. The specimens of *T. vulgaris* identified in this study may have relatively narrow muri and are in this respect similar to *T. parvus*. Srivastava (1969) indicated that the muri of *T. vulgaris* are typically about 1.0 µm wide, whereas the muri on *T. parvus* are about 0.5 µm wide. In addition, the lumen on *T. parvus* are uniformly 0.3 µm in diameter, whereas the lumen on *T. vulgaris* vary from 0.1 to 1.0 µm in diameter. In concurrence with the species diagnosis, the specimens of *T. vulgaris* identified in this study have lumen of variable size.

Infraturma TETRADOTRICOLPATI Rueda-Gaxiola 1969

Genus *Ajatipollis* Krutzsch 1970

139 *Ajatipollis* sp. A of Doyle and Robbins 1977

Plate 6, figure 14

Remarks. A single corroded tetrad measuring 44 µm is tentatively assigned to this genus. Individual grains are 21 µm in diameter with a wall 1.5 µm thick. The corroded reticulum apparently consists of muri 1.0 µm high and 0.3 µm wide separating equidimensional lumen less than 1.0 µm in diameter. The colps are not visible.

Genus *Senecotetradites* Dettmann 1973

176 *Senecotetradites amiantopollis* Srivastava 1975

Plate 6, figure 15

Remarks. A single broken and corroded tetrad was identified from the Blackstone Formation. The three cells are 20 µm in diameter with each grain measuring about 10 µm in diameter. The corroded reticulum consists of muri about 0.3 µm wide separating lumen about 1.0 µm in diameter. Ward (1986) suggested that *Ajatipollis* sp. A of Doyle and Robbins (1977) is conspecific with *S. amiantopollis*. All of the tetrads identified in this study are too corroded to examine in any detail and are kept separated.

177 *Senecotetradites varireticulatus* Dettmann 1973

Plate 6, figure 16

Remarks. A single broken and corroded tetrad 25 µm in diameter consisting of grains about 12 µm in diameter. Low muri about 0.3 µm wide separate irregular lumen 1.5 to 2.0 µm in diameter. The wall is about 1.5 µm thick. One colp is apparently protruding in the equatorial region.

Subturma POLYPTYCHES Naumova 1939

Infraturma PERICOLPATI Rueda-Gaxiola 1967

Genus *Penetetrapites* Hedlund & Norris 1968

162 *Penetetrapites mollis* Hedlund & Norris 1968

Plate 6, figure 17

Remarks. One specimen 27 µm in diameter was located in the Lynx Creek Member. Previous reports suggest that this species first appears in the middle Middle Albian or late Middle Albian (Hedlund and Norris, 1968; Srivastava, 1975; Doyle and Robbins, 1977).

Infraturma STEPHANOCOLPATI van der Hammen 1954

Genus *Quadricolpites* Wingate 1980

155 *Quadricolpites reticulatus* Wingate 1980

Plate 6, figure 18

Remarks. One broken specimen was recovered from the Lynx Creek Member. The equatorial diameter is 41 µm and the broken polar axis is 52 µm. Lumina are round and 3 µm in diameter; muri are 0.75–1.0 µm wide and about 1.0 µm high. The entire wall is about 1.5 µm thick. Previous reports for this species suggest it appears in Upper Albian strata (Ward, 1986)

Subturma PTYCHOTRIPORINES Naumova 1939

Infraturma PROLATI Potonié 1966

Genus *Tricolporoides* Plactová 1971

175 *Tricolporoidites* sp.

Plate 6, figure 19

Remarks. One tricolporoid specimen from the Bruin Creek Member was identified. The grain, measuring 24 µm in

diameter, is microreticulate (muri and lumina 0.25 µm) with a tectate wall about 1.0 µm thick. Superficially resembling *Tricolpites parvus*, the densely stained tricolporoid apertures distinguish this species.

Unassigned pollen and spores

217 recycled Paleozoic

Remarks. Carboniferous spores are uncommonly but routinely observed in the Lynx Creek Member. Likewise, Carboniferous, Permian, and Permo-Triassic spores and gymnosperm pollen are identified as reworked components in the Blackstone Formation. Reworked Paleozoic fossils are less common in the Bruin Creek Member.

FUNGI

Genus *Brachysporisporites* Lange & Smith 1971

129 *Brachysporisporites pyriformis* Lange & Smith 1971

Genus *Dyadosporites* van der Hammen 1954

126 *Dyadosporites ellipsus* Clarke 1965

Plate 7, figure 1

Remarks. Pores protrude slightly and a small atrium may be developed.

130 *Dyadosporites* sp. 1

Plate 7, figure 2

Remarks. Specimens typically have simple apical pores and no atrium.

132 *Dyadosporites* sp. 2

Plate 7, figure 3

Remarks. A single specimen identified from the Lynx Creek Member with a prominent atrium and a small, annulate pore.

Genus *Pluricellaesporites* van der Hammen 1954

125 *Pluricellaesporites psilatus* Clarke 1965

Plate 7, figure 4

Remarks. A common species widely distributed throughout the section.

127 Fungal Hyphae form 1

Plate 7, figure 5

Remarks. Broken filaments consisting of elongate psilate cells that may branch. The septum is entire.

128 Fungal Hyphae form 2

Plate 7, figure 6

Remarks. Broken filaments consisting of equidimensional, rounded, barrel shaped, psilate cells 7 µm wide and with a wall 0.3 µm thick. Septum split or perforate.

131 Fungal tetrad

Plate 7, figure 7

Remarks. Apparently aporate, tetracellate tetrads 25 µm in diameter consisting of cells 12 µm in diameter. Wall 0.8 µm thick is typically split or cracked.

ALGAE

Division PYRRHOPHYTA Pasher 1914

Class DINOPHYCEAE Fritsch 1929

Order PERIDINIALES Haeckel 1894

190 Peridiniales unknown

Remarks. Broken, folded and otherwise unidentifiable dinoflagellates.

Family CERATIACEAE Lindemann 1928

189 Ceratiaceae *sensu* Bint 1986

Remarks. Broken, folded and otherwise unidentifiable dinoflagellates showing some of the characteristics described by Bint (1986) for Ceratiaceae of the western interior of North America.

Genus *Balmula* Bint 1986

188 *Balmula tripenta* Bint 1986

Plate 7, figures 8, 9

Remarks. Bint (1986) reported *Balmula tripenta* from the *Inoceramus bellvuensis* zone (Late Albian) of the Kiowa Formation. The specimens from the Lynx Creek Member open the possibility that the range for this taxon extends into the Middle Albian.

Genus *Nyktericysta* Bint 1986

191 *Nyktericysta davisii* Bint 1986

Plate 7, figures 10–12

Remarks. *Nyktericysta davisii* is relatively common in the Lynx Creek Member at Mill Creek. It is infrequently observed in other Middle and Upper Albian strata examined in this region; none were identified in the marine strata of the Bow Island Formation of the Lethbridge area (Burden, unpublished). Bint (1986) suggested that this might represent a paralic, brackish-water species with as yet poorly defined tolerance limits.

Genus *Odontochitina* Deflandre emend. Bint 1986

209 *Odontochitina operculata* (Wetzel)

Deflandre & Cookson 1955

200 *Odontochitina singhii* Morgan 1980

Plate 7, figure 13

Remarks. Illustrated specimen consists of an extremely long horn. Other species typically have three subequal horns.

Genus *Pseudoceratium* Gocht emend. Bint 1986

192 *Pseudoceratium interiorense* Bint 1986

Plate 7, figure 14

Remarks. Bint (1986) reported *P. interiorense* from the Kiowa Formation, where it is particularly abundant in the early Late Albian *Adkinsites bravoensis* zone. Specimens observed in the Lynx Creek Member suggest that the range might be extended into the Middle Albian.

211 *Pseudoceratium polymorphum* (Eisenack) Bint 1986

Genus *Xenascus* Cookson & Eisenack emend. Yun 1981

216 *Xenascus* sp.

Family GONYAULACYSTACEAE Sarjeant & Downie emend. Sarjeant & Downie 1966

Genus *Hurlandsia* Lister & Batten 1988

181 *Hurlandsia* sp. cf. *H. rugarum* (Piasecki) Lister & Batten 1988

Plate 7, figures 15–17

Remarks. Specimens identified as *Hurlandsia* sp. cf. *H. rugarum* are thin walled and commonly folded. Secure identifications are not always possible. Specimens are more abundant in strata containing other brackish-water and marine dinoflagellate species; however, they also occur in strata with few, if any, marine indicators. If *Hurlandsia* sp. cf. *H. rugarum* is not a fully nonmarine taxon reworked and carried into marine settings, it certainly tolerates a wide range of salinities.

Genus *Wigginsiella* Lucas-Clark 1987

215 *Wigginsiella canadense* (Singh) Lucas-Clark 1987

Plate 8, figure 1

Remarks. A single corroded specimen identified in the Blackstone Formation. *Wigginsiella grandstandica* Lucas-Clark has longer spines than *W. canadense*. Singh (1983) reported this species from Cenomanian strata of the Peace river area.

Family APTEODINIACEAE Eisenack emend. Sarjeant & Downie 1974

Genus *Apteodinium* Eisenack 1958

199 *Apteodinium granulatum* Eisenack 1958

Family SPINIFERITACEAE Sarjeant & Downie emend. Norris 1978

Genus *Spiniferites* Mantell emend. Sarjeant 1970

212 *Spiniferites* sp.

Family HYSTRICHOSPHAERIDIACEAE Evitt emend. Norris 1978

Genus *Oligosphaeridium* Davey & Williams 1966

201 *Oligosphaeridium complex* (White) Davey & Williams 1966

210 *Oligosphaeridium pulcherrimum* (Deflandre & Cookson) Davey & Williams 1966

Plate 8, figure 2

Remarks. *Oligosphaeridium pulcherrimum* is but one of many relatively long-ranging and common dinoflagellates found in the Blackstone Formation.

194 *Oligosphaeridium* sp.

Family CLEISTOSPHAERIDIACEAE Sarjeant & Downie 1974

Genus *Cleistosphaeridium* Davey, Downie, Sarjeant & Williams 1966

207 *Cleistosphaeridium multispinosum* (Singh) Brideaux 1971

Plate 8, figure 3

Remarks. *Cleistosphaeridium multispinosum* is but one of many relatively long-ranging and common dinoflagellates found in the Blackstone Formation.

Family BATIACASPHAERACEAE Dörhöfer & Davies 1979

Genus *Batiacasphaera* Drugg 1970

205 *Batiacasphaera* sp.

Family SENONIASPHAERACEAE Norris 1978

Genus *Wallodinium* Loeblich & Loeblich 1968

214 *Wallodinium bidigitatum* (Manum & Cookson) Lentin & Williams 1973

Plate 8, figure 4

Remarks. Singh (1983) suggested that this taxon ranges from (?)Late Albian to Campanian. For this report, it is identified only in the Blackstone Formation.

Family MEMBRANILARNACIACEAE Eisenack emend. Sarjeant & Downie 1966

Genus *Chlamydophorella* Cookson & Eisenack 1958

206 *Chlamydophorella nyei* Cookson & Eisenack 1958

Plate 8, figure 5

Remarks. Widely reported in Aptian through Upper Cretaceous strata, *Chlamydophorella nyei* is commonly observed in marine deposits of Western Canada.

Family PALAEOPERIDINIACEAE Vozzhennikova emend. Sarjeant 1967

Genus *Laciniadinium* McIntyre 1975

196 *Laciniadinium arcticum* (Manum & Cookson) Lentin & Williams 1980

Plate 8, figure 6

Remarks. This species occurs in association with other, typical, marine dinoflagellates in the Lynx Creek Member of the Mill Creek Formation and in the Blackstone Formation.

Genus *Subtilisphaera* Jain & Millepied 1973

204 *Subtilisphaera pirnaensis* (Alberti) Jain & Millepied 1973

Plate 8, figure 7

Remarks. One of a small number of dinoflagellates identified from the Bruin Creek Member, it may be reworked from nearby marine strata.

Dinoflagellate *Incertae sedis*

Genus *Cometodinium* Deflandre & Courteville 1939

197 *Cometodinium whitei* (Deflandre & Courteville) Stover & Evitt 1978

Remarks. Occurring sporadically in the Mill Creek Formation, the strata and associated fossils suggest a brackish-water or marginal-marine environment for this species.

Genus *Fromea* Cookson & Eisenack 1958

208 *Fromea amphora* Cookson & Eisenack emend. Yun 1981

Plate 8, figure 8

Remarks. The larger of the two species identified here, *Fromea amphora* is apparently confined to open-marine deposits.

195 *Fromea* sp. cf. *F. fragilis* (Cookson & Eisenack) Stover & Evitt 1978

Plate 8, figure 9, 10

Remarks. Relatively common in strata of the Lynx Creek Member, *Fromea* sp. cf. *F. fragilis* apparently tolerates wide variations in salinity.

Division CHLOROPHYTA Pascher 1914

Class CHLOROPHYCEAE Kützing 1843

Order CHLOROCOCCALES Marchand 1895

Family CHLORELLACEAE (Wille) Brunnthaler 1913

Genus *Tetraedron* Kützing 1845

184 *Tetraedron* sp.

Plate 8, figure 11

Remarks. A single specimen identified from near the base of the Lynx Creek Member, *Tetraedron* sp. is typically found as part of the phytoplankton in modern freshwater environments. It is less commonly identified with other fossil detritus in marginal-marine deposits (e.g. Mackenzie River prodelta silts and clays). This association, and, by comparison, that for the Lynx Creek Member suggests derivation from nearby, nonmarine settings.

Family HYDRODICTYACEAE (Gray) Dumortier 1829

Genus *Pediastrum* (Turpin) Meneghini 1840

182 *Pediastrum* sp.

Plate 8, figure 12

Remarks. *Pediastrum* sp. is a widely distributed freshwater alga found in Cretaceous and younger strata. Commonly observed in marginal-marine settings, it may be part of the freshwater plume coming from nearby rivers.

Family SCENEDESMACEAE Oltmanns 1904

Genus *Scenedesmus* Meyen 1829

183 *Scenedesmus* sp.

Plate 8, figures 13, 14

Remarks. Not commonly preserved in strata, *Scenedesmus* sp. is commonly reported as a part of the freshwater phytoplankton of modern ponds, streams and marshes. The fossil association identified for this species in the Lynx Creek Member suggests that it too may be carried into marginal-marine settings.

Order ZYGNEMATALES Borge & Pascher 1931

Family ZYGNEMATACEAE (Meneghini) Kützing 1898

Genus *Schizophacus* Pierce 1976

180 *Schizophacus* sp.

Plate 8, figure 15

Remarks. A commonly identified, nonmarine, freshwater fossil that commonly occurs in marginal-marine and marine settings.

Genus *Tetranguladinium* Yu, Guo & Mao 1983

179 *Tetranguladinium conspicuum* Yu, Guo & Mao 1983

Plate 8, figure 16

Remarks. A freshwater algal reproductive body mistakenly identified by Batten and Lister (1988) as a dinoflagellate.

Genus *Tetraporina* Naumova ex. Naumova 1950

186 *Tetraporina horologia* (Staplin) Playford 1963

Plate 8, figure 17

Remarks. A freshwater algal reproductive body known from strata as old as Carboniferous. Singh (1971) reported this species from the Paddy Member of the Peace River Formation and the lower Shaftesbury Formation of the Peace River area. The single specimen identified here occurs in the Lynx Creek Member.

Division PRASINOPHYTA Round 1971

Order PTEROSPERMATALES Schiller 1925

Family TASMANITACEAE Sommer 1956

Genus *Chomotriletes* Naumova emend. Hart 1964

178 *Chomotriletes minor* (Kedves) Pocock 1970

Plate 8, figure 18

Remarks. A long-ranging fossil thought to be associated with freshwater settings.

Genus *Tasmanites* Newton emend. Eisenack 1958

193 *Tasmanites* sp.

Plate 8, figure 19

Remarks. A long-ranging genus with a wide range of environmental affinities, the specimens identified in this study are confined to the Lynx Creek Member.

Family CYMATIOSPHAERACEAE Mädler 1963

Genus *Schizosporis* Cookson & Dettmann emend. Pierce 1976

185 *Schizosporis reticulatus* Cookson & Dettmann 1959

Family PTEROSPERMELLACEAE Eisenack 1972

Genus *Pterospermella* Eisenack 1972

202 *Pterospermella harti* (Sarjeant) Eisenack & Cramer 1973

Plate 8, figure 20

Remarks. A long-ranging taxon typically found in marine deposits, the fossils identified from Beaver Mines and Mill Creek strata are thought to be reworked.

INCERTAE SEDIS

Group ACRITARCHA Evitt 1963

Subgroup ACANTHOMORPHITAE Downie, Evitt & Sarjeant 1963

Genus *Micrhystridium* Deflandre emend. Downie & Sarjeant 1963

187 *Micrhystridium* sp.

Plate 8, figure 21

Remarks. One of many specimens and species occurring in small numbers throughout the section.

Subgroup POLYGONOMORPHITAE Downie, Evitt & Sarjeant 1963

Genus *Veryhachium* Deunff emend. Downie & Sarjeant 1963

213 *Veryhachium europaeum* Stockmans & Willière 1960

203 *Veryhachium rhomboidium* Downie 1959

Plate 8, figure 22

Remarks. A typical example of the small numbers of *Veryhachium* identified in this study.

Acritarch *Incertae sedis*

Genus *Lecaniella* Cookson & Eisenack 1962

198 *Lecaniella foveata* Singh 1971

Plate 8, figure 23

Remarks. *Lecaniella foveata* was first identified from the Upper Albian Paddy Member of the Peace River area (Singh, 1971). The poorly preserved specimens identified here suggest that the range for this taxon extends into the Middle Albian.

References

Adair, R.N.
1986: The pyroclastic rocks of the Crowsnest Formation, Alberta: M.Sc. thesis, University of Alberta, 196 p.

Allan, J.A. and Carr, J.L.
1947: Geology of the Highwood-Elbow area, Alberta; Research Council of Alberta, Report 49, p. 1-74.

Amajor, L.C.
1985: Biotite grain size distribution and source area of the Lower Cretaceous Viking bentonites, Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 33, p. 471-478.

Anderson, F.D.
1951: The McDougall-Segur Conglomerate; M.Sc. thesis, McGill University, 52 p.

Aubrey, W.M.
1989: Mid-Cretaceous alluvial-plain incision related to eustasy, southeastern Colorado Plateau; Geological Society of America, Bulletin, v. 101, p. 443-449.

Batten, D.J. and Lister, J.K.
1988: Evidence of freshwater dinoflagellates and other algae in the English Wealden (Early Cretaceous); Cretaceous Research, v. 9, p. 171-179.

Beach, H.H.
1943: Marble Mountain map-area, Alberta; Geological Survey of Canada Paper 42-3, p. 1-21.

Bell, W.A.
1956: Lower Cretaceous floras of Western Canada; Geological Survey of Canada, Memoir 285, 331 p.

Berry, E.W.
1929a: The Kootenay and Lower Blairmore floras; *in* Mesozoic Palaeontology of Blairmore Region, Alberta; National Museum of Canada, Bulletin 58, p. 28-54.

1929b: The Upper Blairmore Flora; *in* Mesozoic palaeontology of Blairmore Region, Alberta; National Museum of Canada Bulletin 58, p. 55-65.

Bint, A.N.
1986: Fossil Ceratiaceae: a restudy and new taxa from the mid-Cretaceous of the Western Interior, U.S.A; Palynology, v. 10, p. 135-180.

Bloch, J., Schröder-Adams, C., Leckie, D.A., McIntyre, D.J., Craig, J., and Staniland, M.
1993: Revised stratigraphy of the lower Colorado Group (Albian - Turonian), western Canada; Bulletin of Canadian Petroleum Geology, v. 41, p. 325-348.

Boyle, R.W.
1979: The geochemistry of gold and its deposits; Geological Survey of Canada, Bulletin 280, 584 p.

Brenner, G.J.
1963: The spores and pollen of the Potomac Group of Maryland; Maryland Department of Geology, Mines and Water Resources, Bulletin, v. 27, 215 p.

Burden, E.T.
1984: Terrestrial palynomorph biostratigraphy of the lower part of the Mannville Group (Lower Cretaceous), Alberta and Montana; *in* The Mesozoic of Middle North America, (ed.) D.F. Stott and D.J. Glass, Memoir 9, Canadian Society of Petroleum Geologists, p. 249-269.

Burden, E.T. and Hills, L.V.
1989: Illustrated key to genera of Lower Cretaceous terrestrial palynomorphs (excluding megaspores) of Western Canada; American Association of Stratigraphic Palynologists, Contributions Series, v. 21, 147 p.

Cant, D.J.
1984: Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposit; Journal of Sedimentary Petrology, v. 54, p. 541-556.

Cheel, R.J. and Leckie, D.A.
1990: A tidal-inlet complex in the Cretaceous epeiric sea of North America: Virgelle Member, Milk River Formation, southern Alberta, Canada; Sedimentology, v. 37, p. 67-81.

Clow, W.H.A. and Crockford, M.B.B
1951: Geology of Lynx Creek River area, Alberta; Research Council of Alberta, Report 59, p. 1-70.

Craw, D. and Leckie, D.A.
1996: Tectonic controls on detrital gold dispersal into a foreland basin: an example from the Western Canada Sedimentary Basin; Journal of Sedimentary Research, v. 66, p. 559-566.

Dawson, G.M.
1886: Preliminary report on the physical and geological features of that portion of the Rocky Mountains between latitudes 49 degrees and 51 degrees 30 minutes; Geological Survey of Canada Annual Report (new series) 1885, v. 1, p. 1-169B.

Dawson, J.W.
1886: On the Mesozoic floras of the Rocky Mountain region of Canada; Royal Society of Canada, Transactions, 3(4), p. 1-22.

Dettmann, M.E.
1973: Angiospermous pollen from Albian to Turonian sediments of eastern Australia; Geological Society of Australia, Special Publication v. 4, p. 3-34.

Dolson, J., Muller, D., Evetts, M.J., and Stein, J.A.
1991: Regional paleotopographic trends and production, Muddy Sandstone (Lower Cretaceous), Central and Northern Rocky Mountains; American Association of Petroleum Geologists Bulletin, v. 75, p. 409-435.

Douglas, R.J.W.
1950: Callum Creek, Langford Creek and Gap map-areas, Alberta; Geological Survey of Canada, Memoir 255, 124 p.

Doyle, J.A. and Robbins, E.I.
1977: Angiosperm pollen zonation of the continental Cretaceous of the Atlantic Coastal Plain and its application to deep wells in the Salisbury Embayment; Palynology, v. 1, p. 43-78.

Fermor, P.R. and Moffat, I.W.
1992: Tectonics and structure of the Western Canada Foreland Basin; *in* Foreland Basins and Foldbelts, (ed.) R.W. Macqueen and D.A. Leckie; American Association of Petroleum Geologists, Memoir 55, p. 81-106.

Folinsbee, R.E., Baadsgaard, H., and Lipson, J.
1961: Potassium - Argon dates of Upper Cretaceous ash falls, Alberta, Canada; New York Academy of Science, Annals, v. 91(2), p. 352-363.

Folinsbee, R.E., Ritchie, W.D., and Stransberry, G.F.
1957: The Crowsnest Volcanics and Cretaceous geochronology; 7th Annual Field Conference, Alberta Society of Petroleum Geologists, p. 20-26.

Glaister, R.P.
1959: Lower Cretaceous of southern Alberta and adjoining areas; American Association of Petroleum Geologists, Bulletin, v. 43, p. 590-640.

Hage, C.O.
1943: Beaver Mines, Alberta; Geological Survey of Canada, Map 827A.

Hedlund, R.W. and Norris, G.
1968: Spores and pollen grains from Fredericksburgian (Albian) Strata, Marshall County, Oklahoma; Pollen et Spores, v. 10(1), p. 129-159.

Howard, J.D. and Reineck, H.E.
1981: Depositional facies of high energy beach to offshore sequence: comparison with low energy sequence; American Association of Petroleum Geologists, Bulletin, v. 66, p. 807-830.

Hume, G.S.
1930: The Highwood-Jumpingpound anticline, with notes on Turner Valley, New Black Diamond, and Priddis Valley structures, Alberta; Geological Survey of Canada, Summary Report, 1929, p. 1-24.

1938: The stratigraphy and structure of southern Turner Valley, Alberta; Geological Survey of Canada, Paper 38-22, 21 p.

1939: The stratigraphy and structure of Turner Valley, Alberta; Geological Survey of Canada, Paper 39-4, 19 p.

Jansonius, J. and Hills, L.V.
1976: Genera file of fossil spores and pollen; Special Publication, Department of Geology, University of Calgary.

Leach, W.W.
1912: Geology of the Blairmore map-area, Alberta; Geological Survey of Canada, Summary Report 1911, p. 192-200.

1914: Blairmore map-area, Alberta; Geological Survey of Canada, Summary Report 1912, Map 107A, opposite p. 234.

Leckie, D.A.
1986: Rates, controls, and sand-body geometries of transgressive-regressive cycles: Cretaceous Moosebar and Gates formations, British Columbia; American Association of Petroleum Geologists, Bulletin, v. 70, p. 516-535.

1988: Wave-formed, coarse-grained ripples and their relationship to hummocky cross-stratification; Journal of Sedimentary Petrology, v. 58, p. 607-622.

1989: Sedimentology and sequences of the Paddy and Cadotte members along the Peace River; Canadian Society of Petroleum Geologists, Field guide to Second International Symposium on Clastic Tidal Deposits, August 22-25, Calgary, 78 p.

Leckie, D.A. and Cheel, R.J.
1997: Sedimentology and depositional history of Lower Cretaceous coarse-grained clastics, southwest Alberta and southeast British Columbia; Bulletin of Canadian Petroleum Geology, v. 45, p.1-24.

Leckie, D.A. and Craw, D.
1995: Westerly-derived Early Cretaceous gold paleoplacers in the Western Canada foreland basin, southwestern Alberta: tectonic and economic implications; Canadian Journal of Earth Sciences, v. 32, p. 1079-92.

Leckie, D.A. and Krystinik, L.F.
1989: Is there evidence for geostrophic currents in the sedimentary record of inner to middle-shelf deposits; Journal of Sedimentary Petrology, v. 59, p. 862-870.

1995: Cretaceous igneous-clast conglomerate in the Blairmore Group, Rocky Mountain Foothills and adjacent subsurface (Bow Island Formation), Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 43, p. 320-342.

Leckie, D.A. and Reinson, G.E.
in press: Effects of Middle to Late Albian sea level fluctuations in the Cretaceous Interior Seaway, Western Canada; *in* Evolution of the Western Interior Basin, (ed.) W.G.E. Caldwell and E.G. Kauffman; Geological Association of Canada, Special Publication, p.151-175.

Leckie, D.A. and Singh, C.
1991: Estuarine deposits of the Albian Paddy Member (Peace River Formation) and lowermost Shaftesbury Formation, Alberta, Canada; Journal of Sedimentary Petrology, v. 61, p. 825-849.

Leckie, D. and Smith, D.
1992: Regional setting, evolution and depositional cycles of the Western Canadian Foreland Basin; *in* Foreland Basins and Foldbelts, (ed.) R.W. Macqueen and D.A. Leckie; American Association of Petroleum Geologists, Memoir 55, p. 9-46.

Leckie, D.A. and Walker, R.G.
1982: Storm and tide-dominated shorelines in the Cretaceous Moosebar-Lower Gates interval – outcrop equivalents of the Deep Basin gas trap in Western Canada; American Association of Petroleum Geologists, Bulletin, v. 66, p. 138-157.

Levinson, A.A.
1980: Introduction to exploration geochemistry; Applied Publishing, Wilmette, Illinois, 924 p.

McCarthy, P.J., Martini, I.P., and Leckie, D.A.
1997a: Anatomy and evolution of a Lower Cretaceous alluvial plain - sedimentology and paleosols in the Upper Blairmore Group, southwestern Alberta; Sedimentology, v. 44, p. 197-220.

1997b: Pedosementary history and floodplain dynamics of the Lower Cretaceous Mill Creek Formation, southwestern Alberta, Canada; Canadian Journal of Earth Sciences, v. 34, p. 598-617.

McCarthy, P.J., Martini, I.P., Evans, L.J., and Leckie, D.A.
1998: Pedogenic and diagenetic influences on void coating formation in Lower Cretaceous paleosols of the Mill Creek Formation, southwestern Alberta, Canada; Geoderma, v. 87, p. 209-237.

McCubbin, D.G.
1982: Barrier-island and strand plain facies; *in* Sandstone Depositional Environments, (ed.) P.A. Scholle and D. Spearing; American Association of Petroleum Geologists Memoir 31, p. 247-280.

McLean, J.R.
1982: Lithostratigraphy of the Lower Cretaceous coal-bearing sequence of the foothills of Alberta; Geological Survey of Canada, Paper 80-29, 46 p.

McLearn, F.H.
1929b: Stratigraphic paleontology; *in* Mesozoic Palaeontology of Blairmore Region, Alberta; National Museum of Canada Bulletin, v. 58, p. 80-107.

McMechan, M.E. and Thompson, R.I.
1993: The Canadian Cordilleran fold and thrust belt south of 66° N and its influence on the Western Interior Basin; *in* Evolution of the Western Interior Basin, (ed.) W.G.E. Caldwell and E. Kauffman; Geological Association of Canada, Special Paper, v. 39, p. 73-90.

McNeil, D.H. and Caldwell, W.G.E.
1981: Cretaceous rocks and their foraminifera in the Manitoba escarpment; Geological Association of Canada, Special Paper 21, 438 p.

Meijer Drees, N.C. and Mhyr, D.W.
1981: The Upper Cretaceous Milk River and Lea Park formations in southeastern Alberta; Bulletin of Canadian Petroleum Geology, v. 29, p. 42-74.

Mellon, G.B.
1967: Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains; Research Council of Alberta, Bulletin 21, 270 p.

Mellon, G.B. and Wall, J.H.
1961. Correlation of the Blairmore Group and equivlent strata; Edmonton Geological Society Quarterly, v. 5, 11 p.

1963: Correlation of the Blairmore Group and equivalent strata; Bulletin of Canadian Petroleum Geology, v. 11(4), p. 396-409.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J.
1982: Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera; Geology, v. 10, p. 75-79.

Nguyen, E.K., Sinclair, A.J., and Libby, W.G.
1968: Age of the northern part of the Nelson Batholith; Canadian Journal of Earth Sciences, v. 5, p. 955-957.

Norris, D.K.
1958: Beehive Mountain, British Columbia and Alberta; Geological Survey of Canada, Paper 58-5.

1964: The Lower Cretaceous of the southeastern Canadian Cordillera; Bulletin of Canadian Petroleum Geology, v. 12, 14th Annual Field Conference Guidebook Issue (August, 1964), p. 512-535.

Norris, D.K., Stevens, R.D., and Wanless, R.K.
1965: K-Ar age of igneous pebbles in the Mcdougall-Segur Conglomerate, southeastern Canadian Cordillera; Geological Survey of Canada, Paper 65-26, 11 p.

Norris, G.
1967: Spores and pollen from the lower Colorado Group (Albian-Cenomanian) of central Alberta; Palaeontographica, Abt B, Band 120, p. 72-115.

Obradovich, J.
1993: A Cretaceous time scale; *in* Evolution of the Western Interior Basin, (ed.) W.G.E. Caldwell and E. Kauffman, Geological Association of Canada, Special Paper 39, p. 379-396.

Parrish, R.R. and Wheeler, J.O.
1983: A U-Pb zircon age of the Kaskanax batholith, southeastern British Columbia; Canadian Journal of Earth Sciences, v. 20, p. 1751-1756.

Pearce, T.H.
1970: The analcite-bearing volcanic rocks of the Crowsnest Formation, Alberta; Canadian Journal of Earth Sciences, v. 7, p. 46-66.

Playford, G.
1971: Palynology of Lower Cretaceous (Swan River) strata of Saskatchewan and Manitoba; Palaeontology, v. 14, p. 533-565.

Porter, J.W.
1992: Conventional hydrocarbon reserves of the Western Canada Foreland Basin; *in* Foreland Basins and Foldbelts, (ed.) R.W. Macqueen and D.A. Leckie; American Association of Petroleum Geologists, Memoir 55, p. 159-189

Porter, J.W., Price, R.A., and McGrossan, R.G.
1981: The Western Canada Sedimentary Basin; Philosophical Transactions of the Royal Society of London, v. A305, p. 169-192.

Price, R.A.
1962: Fernie map-area, east half, Alberta and British Columbia; Geological Survey of Canada, Paper 61-24, 65 p.

1981: The cordilleran foreland thrust and fold belt in the southern Canadian Rocky Mountains; *in* Thrust and Nappe Tectonics, (ed.) R.M. McClay and N.J. Price; Geological Society of London, Special Publication 9, p. 427-448.

Reinson, G.E., Warters, W.J., Cox, J., and Price, P. R.
1994: Cretaceous Viking Formation of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, (comp.) G.D. Mossop and I. Shetsen; Canadian Society of Petroleum Geologists, p. 353-363.

Ricketts, B.D.
1982: Laharic breccias from the Crowsnest Formation, southern Alberta; *in* Current Research, Part A; Geological Survey of Canada, Paper 1982-1A, p. 83-87.

Riley, D., Primrose, T., and Dempsey, H.
1968: The Lost Lemon Mine; Frontier Publishing, Calgary, Canada, 40 p.

Rose, B.
1917: Crownest coal field, Alberta; Geological Survey of Canada, Summary Report 1916, p. 107-114.

Scott, R.W.
1970a: Paleoecology and paleontology of the Lower Cretaceous Kiowa Formation, Kansas University of Kansas Paleontological Contributions 52, 94 p.

1970b: Stratigraphy and sedimentary environments of Lower Cretaceous rocks, southern Western Interior; American Association of Petroleum Geologists, Bulletin, v. 54, p. 1225-1244.

Scott, R.W. and Taylor, A.M.
1977: Early Cretaceous environments and communities in the southern Western Interior; Mountain Geologist, v. 14, p. 155-173.

Singh, C.
1964: Microflora of the Lower Cretaceous Mannville Group, east-central Alberta; Research Council of Alberta, Bulletin 15, 239 p.

1971: Lower Cretaceous microfloras of the Peace River area, northwestern Alberta; Research Council of Alberta, Bulletin 28, 542 p.

1983: Cenomanian microfloras of the Peace River area, northwestern Alberta; Research Council of Alberta, Bulletin 44, 322 p.

Srivastava, S.K.
1969: Some angiosperm pollen from the Edmonton Formation (Maastrichtian), Alberta, Canada; J. Sen Memorial Committee and Botanical Society of Bengal, Calcutta, India, p. 47-67.

1975: Microspores from the Fredericksburg Group (Albian) of the Southern United States; Paleobiologie Continentale, v. 6, 119 p.

Stelck, C.R.
1958: Stratigraphic position of the Viking sand; Journal of the Alberta Society of Petroleum Geologists, v. 6, p. 2-7.

Stelck, C.R., et al.
1972: The Cretaceous and Jurassic of the Foothills of the Rocky Mountains of Alberta; 24th International Geological Congress, Field Excursion A20 Guidebook, 51 p.

Stelck, C.R. and Leckie, D.A.
1990: Biostratigraphic constraints and depositional environment of the Lower Cretaceous (Albian) Boulder Creek Formation, Monkman area, British Columbia; Canadian Journal of Earth Sciences, v. 27, p. 452-458.

Stelck, C.R., Wall, J.H., Bahan, W.G., and Martin, L.J.
1956: Middle Albian Foraminifera from Athabasca and Peace drainage areas of western Canada; Research Council of Alberta, Report 75, 60 p.

Stott, D.F.
1982: Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the foothills and plains of Alberta, British Columbia, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Bulletin 328, 124 p.

Urbatt, R.R.
1988: Provenance of the Lower Cretaceous (Albian) McDougall-Segur Conglomerate, southwestern Alberta; B.Sc. thesis, University of Calgary, 85 p.

Ward, J.V.
1986: Early Cretaceous angiosperm pollen from Cheyenne and Kiowa Formations (Albian) of Kansas, U.S.A.; Palaeontographica, Abt B, Band 202, p. 1-81.

Weimer, R.J.
1983: Relation of unconformites, tectonics and sea level changes, Cretaceous of the Denver Basin and adjacent areas; *in* Mesozoic Paleogeography of West-Central United States, (ed.) M.W. Reynolds and E.D. Doly; Society of Economic Paleontologists Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 2, p. 359-376.

Wickenden, R.T.D.
1951: Some Lower Cretaceous sections on the Peace River below the mouth of the Smokey River, Alberta; Geological Survey of Canada, Paper 51-16, 47 p.

Wingate, F.H.
1980: Plant microfossils from the Denton Shale Member of the Bokchito Formation (Lower Cretaceous, Albian) in southern Oklahoma; Oklahoma Geological Survey, Bulletin 130, 93 p.

Yanagi, T., Baadsgaard, H., and Stelck, C.R.
1988: Radiometric dating of a tuff bed in the middle Albian Hulcross Formation at Hudson's Hope, British Columbia; Canadian Journal of Earth Sciences, v. 25, p. 1123-1127.

APPENDIX 1
ALPHABETICAL LISTING OF TAXA

SPORES AND PREPOLLEN

65 *Aequitriradites variabilis* Pocock 1962
32 *Aequitriradites verrucosus* (Cookson & Dettmann) Cookson & Dettmann 1961
38 *Appendicisporites cristatus* (Markova) Pocock 1964
88 *Appendicisporites erdtmanii* Pocock 1964
67 *Appendicisporites matesovae* (Bolchovitina) Norris 1967
17 *Appendicisporites potomacensis* Brenner 1963
16 *Appendicisporites problematicus* (Burger) Singh 1971
95 *Appendicisporites spinosus* Pocock 1964
59 *Appendicisporites tricostatus* (Bolchovitina) Pocock 1964
43 *Appendicisporites unicus* (Markova) Singh 1964
45 *Baculatisporites comaumensis* (Cookson) Potonié 1956
18 *Biretisporites potoniaei* Delcourt & Sprumont 1955
80 *Callialasporites dampieri* (Balme) Dev 1961
101 *Camarozonotriletes ambigens* (Frankina) Playford 1971
11 *Ceratosporites pocockii* Srivastava 1972
99 *Cibotiidites robusta* (Brenner) n. comb.
52 *Cicatricosisporites annulatus* Archangelsky & Gamerro 1966
8 *Cicatricosisporites australiensis* (Cookson) Potonié 1956
81 *Cicatricosisporites crassistriatus* Burger 1966
100 *Cicatricosisporites* sp. cf. *C. crassiterminatus* Hedlund 1966
6 *Cicatricosisporites hallei* Delcourt & Sprumont 1955
3 *Cicatricosisporites hughesi* Dettmann 1963
102 *Cicatricosisporites imbricatus* (Markova) Singh 1971
26 *Cicatricosisporites minor* (Bolkhovitina) Pocock 1964
83 *Cicatricosisporites mohrioides* Delcourt & Sprumont 1955
97 *Cicatricosisporites patapscoensis* Brenner 1963
57 *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
73 *Cicatricosisporites subrotundus* Brenner 1963
40 *Cicatricosisporites venustus* Deák 1963
68 *Cicatricososporites phaseolus* (Delcourt & Sprumont) Krutzsch 1959
19 *Concavisporites jurienensis* Balme 1957
61 *Concavissimisporites asper* (Bolkhovitina) Pocock 1962
91 *Concavissimisporites parkinii* (Pocock, 1962) Singh 1964
21 *Concavissimisporites penolaensis* Dettmann 1963
42 *Concavissimisporites variverrucatus* (Couper) Brenner 1963
85 *Contignisporites glebulentus* Dettmann 1963
39 *Costatoperforosporites foveolatus* Deák 1962
31 *Couperisporites complexus* (Couper) Pocock 1962
7 *Cyathidites minor* Couper 1953
28 *Deltoidospora diaphana* Wilson & Webster 1946
1 *Deltoidospora hallii* Miner 1935
20 *Deltoidospora psilostoma* Rouse 1959
9 *Dictyophyllidites* sp.
90 *Distaltriangulisporites irregularis* Singh 1971
62 *Distaltriangulisporites mutabilis* Singh 1971
35 *Distaltriangulisporites perplexus* (Singh) Singh 1971
24 *Foraminisporis wonthaggiensis* (Cookson & Dettmann) Dettmann 1963
96 *Foveogleicheniidites confossus* (Hedlund) Burger 1976
12 *Foveotriletes subtriangularis* Brenner 1963
50 *Gleicheniidites bolchovitinae* Döring 1965
4 *Gleicheniidites circiniidites* (Cookson) Dettmann 1963
2 *Gleicheniidites senonicus* Ross 1949
15 *Granulatisporites* sp.
66 *Impardecispora apiverrucata* (Couper) Venkatachala, Kar & Raza 1968
41 *Impardecispora crassa* (Brenner) Burden & Hills 1989
36 *Impardecispora marylandensis* (Brenner) Srivastava 1975
56 *Impardecispora minor* (Pocock) Venkatachala, Kar & Raza 1968
92 *Impardecispora tribotrys* (Dettmann) Venkatachala, Kar & Raza 1968
87 *Interulobites intraverrucatus* (Brenner) Paden Phillips & Felix 1971
70 *Interulobites triangularis* (Brenner) Paden Phillips & Felix 1971
94 *Ischyosporites disjunctus* Singh 1971
27 *Ischyosporites punctatus* Cookson & Dettmann 1958
47 *Januasporites spiniferus* Singh 1964
51 *Klukisporites areolatus* Singh 1971
76 *Klukisporites foveolatus* Pocock 1964
30 *Klukisporites granulatus* (Pocock) Burden & Hills 1989
54 *Klukisporites pseudoreticulatus* Couper 1958
69 *Kraeuselisporites hastilobatus* Playford 1971
10 *Laevigatosporites ovatus* Wilson & Webster 1946
74 *Leptolepidites verrucatus* Couper 1953
79 *Leptolepidites* sp. cf. *L. irregularis* of Wingate 1980
23 *Lophotriletes babsae* (Brenner) Singh 1971
48 *Lycopodiacidites canaliculatus* Singh 1971
86 *Microreticulatisporites uniformis* Singh 1964
98 *Neoraistrickia truncata* (Cookson)Potonié 1956
63 *Ornamentifera baculata* Singh 1971
33 *Osmundacidites wellmanii* Couper 1953
55 *Peromonoletes allensis* Brenner 1963
78 *Pilosisporites brevipapillosus* Couper 1958
22 *Pilosisporites trichopapillosus* (Thiergart) Delcourt & Sprumont 1955
5 *Plicatella crimenensis* (Bolchovitina) Dörhöfer 1977
53 *Polycingulatisporites reduncus* (Bolkhovitina) Playford & Dettmann 1965
71 *Polycingulatisporites* sp. cf. *P. radiatus* Singh 1971
217 Recycled Paleozoic
34 *Retitriletes austroclavatidites* (Cookson) Döring, Krutzsch, Mai & Schulz 1963
37 *Retitriletes clavatoides* (Cookson) Döring, Krutzsch, Mai & Schulz 1963
13 *Retitriletes crassimacerius* (Hedlund) Burden & Hills 1989

46 *Retitriletes singhii* Srivastava 1972
64 *Saxetia kiamichicola* Srivastava 1975
75 *Scopusporis spackmani* (Brenner) Wingate 1980
89 *Sestrosporites pseudoalveolatus* (Couper) Dettmann 1963
14 *Stereisporites antiquasporites* (Wilson & Webster) Dettmann 1963
77 *Stoverisporites lunaris* (Cookson & Dettmann) Burger 1976
49 *Tappanispora reticulata* (Singh) Srivastava 1975
44 *Tappanispora scurranda* (Norris) Srivastava 1975
82 *Taurocusporites segmentatus* Stover 1962
58 *Todisporites minor* Couper 1958
29 *Triporoletes radiatus* (Dettmann) Playford 1971
25 *Triporoletes reticulatus* (Pocock) Playford 1971
93 *Triporoletes singularis* Mtchedlishvili 1960
60 *Undulatisporites undulapolus* Brenner 1963
72 *Verrucosisporites rotundus* Singh 1964

GYMNOSPERM POLLEN

113 *Alisporites bilateralis* Rouse 1959
122 *Alisporites grandis* (Cookson) Dettmann 1963
120 *Araucariacites australis* Cookson 1947
115 *Cedripites canadensis* Pocock 1962
123 *Cedripites cretaceus* Pocock 1962
111 *Cerebropollenites mesozoicus* (Couper) Nilsson 1958
108 *Circulina parva* Brenner 1963
112 *Classopollis* sp.
107 *Cycadopites* sp.
121 *Equisetosporites* sp. cf. *E. pentacostatus* (Brenner) Wingate 1980
109 *Eucommidites* sp.
103 *Inaperturopollenites* sp.
106 *Pityosporites alatipollenites* (Rouse) Singh 1964
114 *Pityosporites constrictus* Singh 1964
116 *Podocarpidites biformis* Rouse 1957
118 *Podocarpidites canadensis* Pocock 1962
119 *Podocarpidites granulatus* Singh 1971
105 *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962
117 *Podocarpidites minisculus* Singh 1964
110 *Pristinuspollenites* sp.
124 *Rugubivesiculites rugosus* Pierce 1961
103 *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1950
104 *Vitreisporites pallidus* (Reissinger) Nilsson 1958

ANGIOSPERM POLLEN

139 *Ajatipollis* sp. A of Doyle and Robbins 1977
149 *Asteropollis asteroides* Hedlund & Norris 1968
154 *Asteropollis trichotomosulcatus* (Singh) Singh 1983
152 *Clavatipollenites hughesii* Couper 1958
160 *Clavatipollenites minutus* Brenner 1963
133 *Clavatipollenites tenellis* Paden Phillips & Felix 1971
165 *Cupuliferoidaepollenites parvulus* (Groot & Penny) Dettmann 1973
150 *Foveotricolpites concinnus* Singh 1971
161 *Liliacidites doylei* Ward 1986
163 *Liliacidites inaequalis* Singh 1971
167 *Liliacidites tectatus* Singh 1983
137 *Liliacidites* sp. D of Doyle and Robbins 1977
159 *Liliacidites* sp. E of Doyle and Robbins 1977
136 *Liliacidites* sp.
162 *Penetetrapites mollis* Hedlund & Norris 1968
170 *Phimopollenites augathellaensis* (Burger) Dettmann 1973
171 *Phimopollenites pannosus* (Dettmann & Playford) Dettmann 1973
155 *Quadricolpites reticulatus* Wingate 1980
142 *Racemonocolpites* sp.
147 *Retimonocolpites crassatus* (Singh) Singh 1983
146 *Retimonocolpites dividuus* Pierce 1961
172 *Retimonocolpites peroreticulatus* (Brenner) Doyle, van Campo & Lugardon 1975
153 *Retimonocolpites reticulatus* (Brenner) Doyle, van Campo & Lugardon 1975
145 *Retimonocolpites textus* (Norris) Singh 1983
173 *Retitrescolpites kempiae* Ward 1986
138 *Retitrescolpites maximus* (Singh) n. comb.
140 *Retitrescolpites vermimurus* (Brenner) n. comb
141 *Retitrescolpites virgeus* (Groot, Penny & Groot) n. comb.
156 *Rousea brenneri* Singh 1983
135 *Rousea georgensis* (Brenner) Dettmann 1973
174 *Rousea marthae* Ward 1986
164 *Rousea miculipollis* Srivastava 1975
144 *Rousea prosimilis* (Norris) Srivastava 1975
176 *Senecotetradites amiantopollis* Srivastava 1975
177 *Senecotetradites varireticulatus* Dettmann 1973
169 *Striatopollis paranea* (Norris) Singh 1971
168 *Striatopollis* sp.
143 *Tricolpites crassimurus* (Groot & Penny) Singh 1971
166 *Tricolpites fragosus* (Hedlund & Norris) Ward 1986
134 *Tricolpites micromunus* (Groot & Penny) Singh 1971
157 *Tricolpites minutus* (Brenner) Dettmann 1973
151 *Tricolpites parvus* Stanley 1965
158 *Tricolpites sagax* Norris 1967
148 *Tricolpites vulgaris* (Pierce) Srivastava 1969
175 *Tricolporoidites* sp.

FUNGI

129 *Brachysporisporites pyriformis* Lange & Smith 1971
126 *Dyadosporites ellipsus* Clarke 1965
130 *Dyadosporites* sp. 1
132 *Dyadosporites* sp. 2
127 Fungal Hyphae form 1
128 Fungal Hyphae form 2
131 Fungal tetrad
125 *Pluricellaesporites psilatus* Clarke 1965

ALGAE

199 *Apteodinium granulatum* Eisenack 1958
188 *Balmula tripenta* Bint 1986
205 *Batiacasphaera* sp.
189 Ceratiaceae *sensu* Bint 1986
206 *Chlamydophorella nyei* Cookson & Eisenack 1958
207 *Cleistosphaeridium multispinosum* (Singh) Brideaux 1971
178 *Chomotriletes minor* (Kedves) Pocock 1970
197 *Cometodinium whitei* (Deflandre & Courteville) Stover & Evitt 1978
208 *Fromea amphora* Cookson & Eisenack emend. Yun 1981
195 *Fromea* sp. cf. *F. fragilis* (Cookson & Eisenack) Stover & Evitt 1978
181 *Hurlandsia* sp. cf. *H. rugarum* (Piasecki) Lister & Batten 1988
196 *Laciniadinium arcticum* (Manum & Cookson) Lentin & Williams 1980
198 *Lecaniella foveata* Singh 1971
187 *Micrhystridium* sp.
191 *Nyktericysta davisii* Bint 1986
209 *Odontochitina operculata* (Wetzel) Deflandre & Cookson 1955
200 *Odontochitina singhii* Morgan 1980
201 *Oligosphaeridium complex* (White) Davey & Williams 1966
210 *Oligosphaeridium pulcherrimum* (Deflandre & Cookson) Davey & Williams 1966
194 *Oligosphaeridium* sp.
182 *Pediastrum* sp.
190 Peridiniales unknown
192 *Pseudoceratium interiorense* Bint 1986
211 *Pseudoceratium polymorphum* (Eisenack) Bint 1986
202 *Pterospermella harti* (Sarjeant) Eisenack & Cramer 1973
183 *Scenedesmus* sp.
180 *Schizophacus* sp.
185 *Schizosporis reticulatus* Cookson & Dettmann 1959
212 *Spiniferites* sp.
204 *Subtilisphaera pirnaensis* (Alberti) Jain & Millepied 1973
193 *Tasmanites* sp.
184 *Tetraedron* sp.
179 *Tetranguladinium conspicuum* Yu, Guo & Mao 1983
186 *Tetraporina horologia* (Staplin) Playford 1963
213 *Veryhachium europaeum* Stockmans & Willière 1960
203 *Veryhachium rhomboidium* Downie 1959
214 *Wallodinium bidigitatum* (Manum & Cookson) Lentin & Williams 1973
215 *Wigginsiella canadense* (Singh) Lucas-Clark 1987
216 *Xenascus* sp.

APPENDIX 2
MEASURED SECTIONS REFERRED TO BUT NOT ILLUSTRATED IN MAIN TEXT BODY

Lithologies

Shale

Siltstone

Sandstone

Conglomerate

Volcanics/tuff

Covered interval

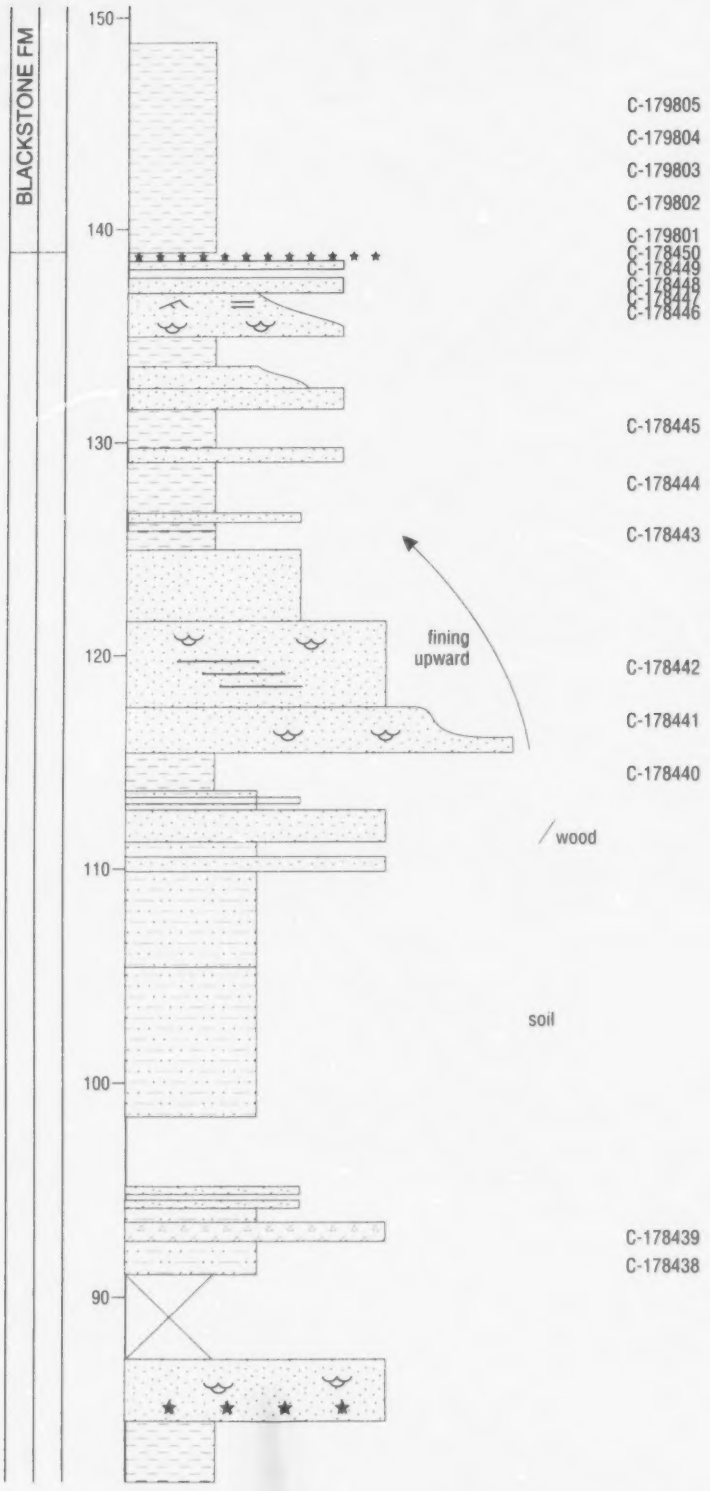
Bentonite/tuff.....xxxxxxxx
Roots.....
Bioturbation.....
Carbonaceous debris.....C
Carbonate concretions (calcite/dolomite).....
Intraformational shale clasts.....
Sandstone clasts.....
Plant impressions.....
Shells.....

Sedimentary structures

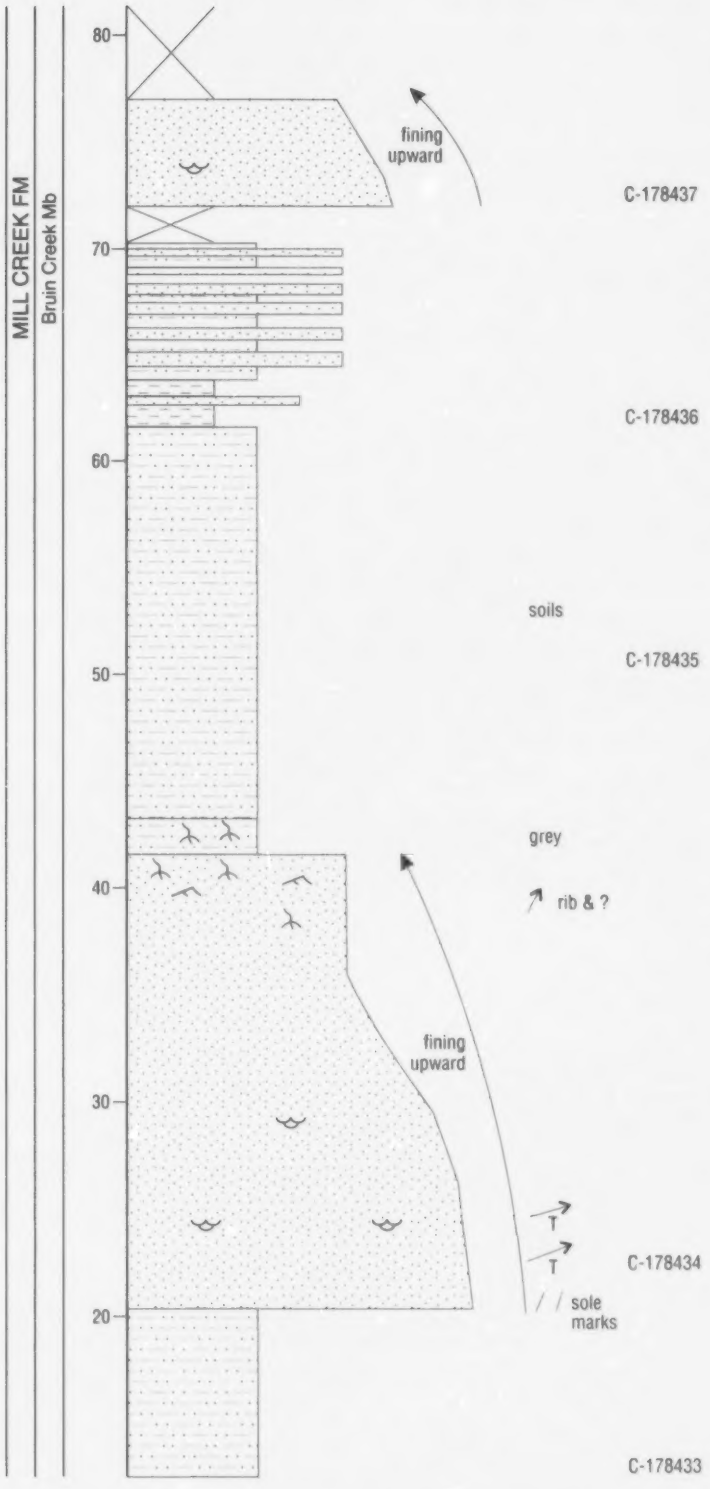
Trough crossbeds.....
Planar tabular crossbeds.....
Current ripples.....
Wave ripples.....
Hummocky cross-stratification.....
Parallel bedding.....

Paleocurrents

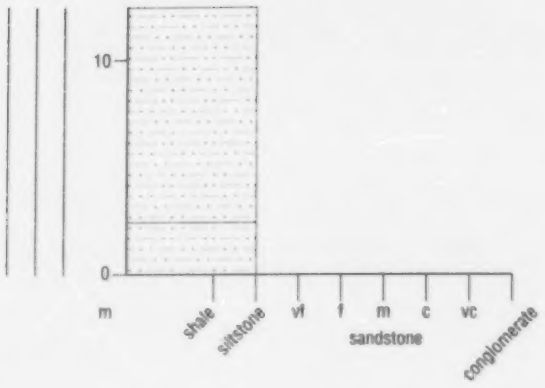
Sense only .....
Direction.....
Wave ripples.....W
Trough crossbeds.....T
Planar tabular crossbeds.....PT



Appendix 2, Figure 1. *Mill Creek 2.*

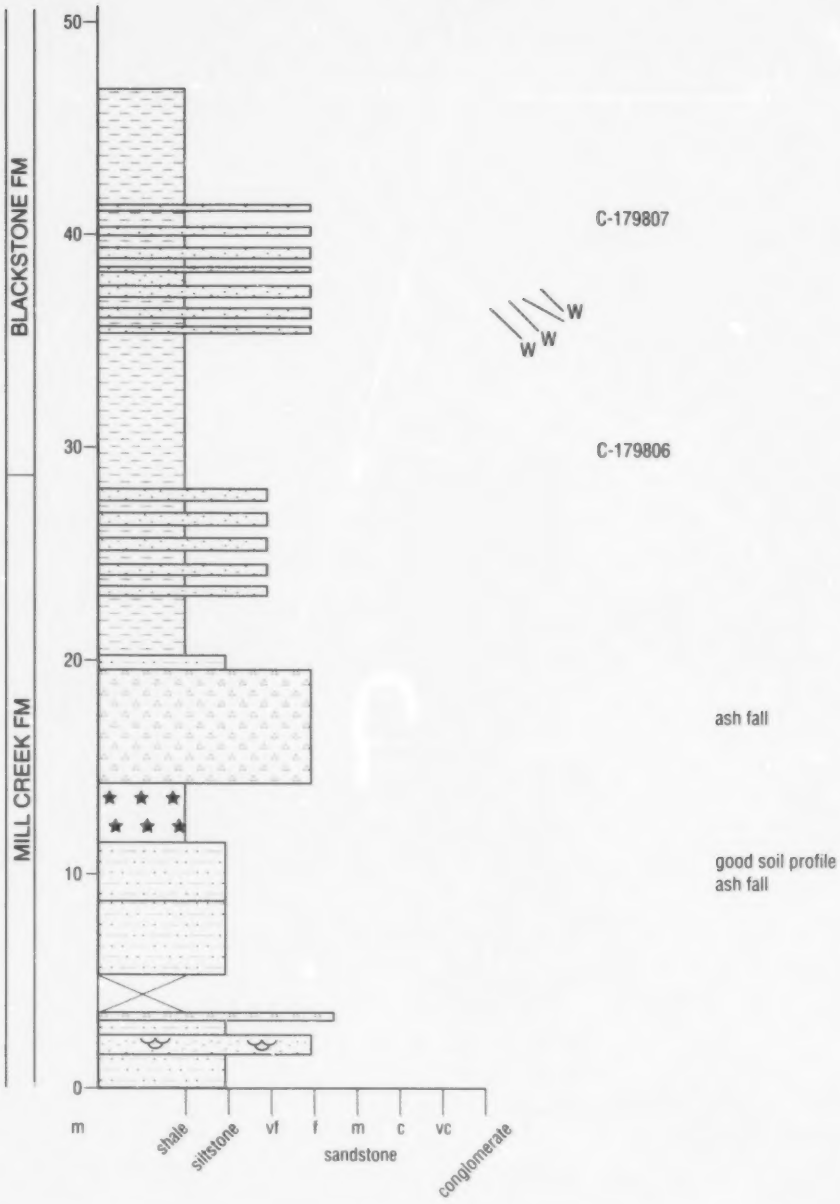


Appendix 2, Figure 1 continued

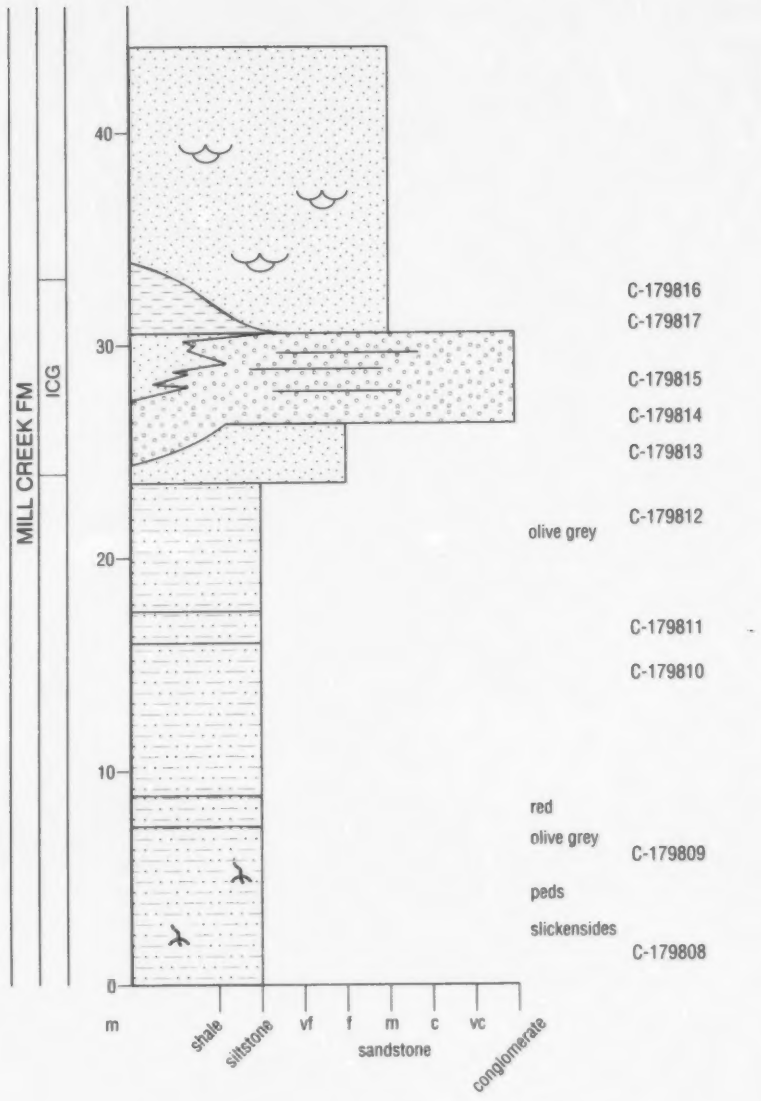


C-178432

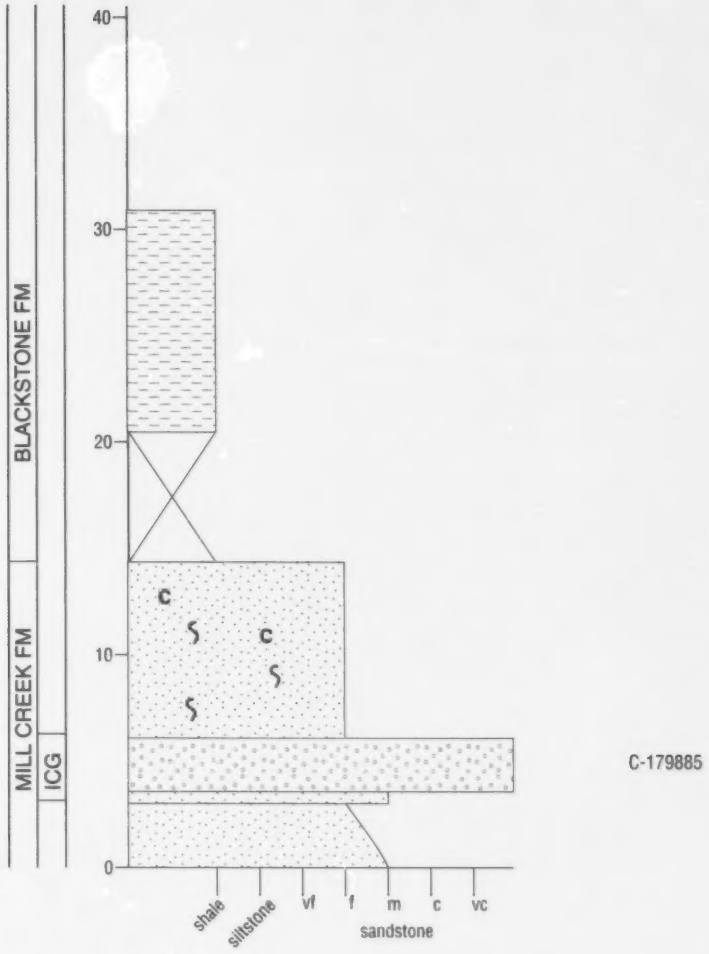
Appendix 2, Figure 1 continued



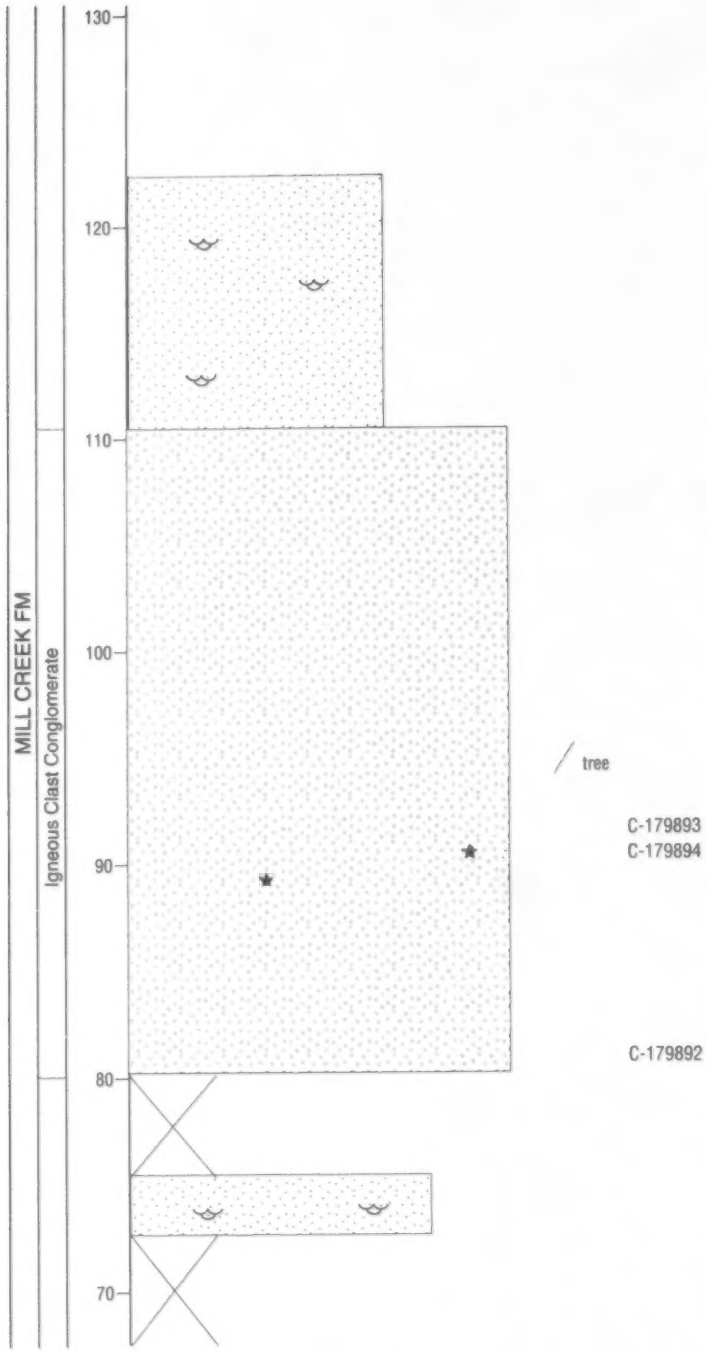
Appendix 2, Figure 2. *Mill Creek 3, Mill Creek Bridge.*



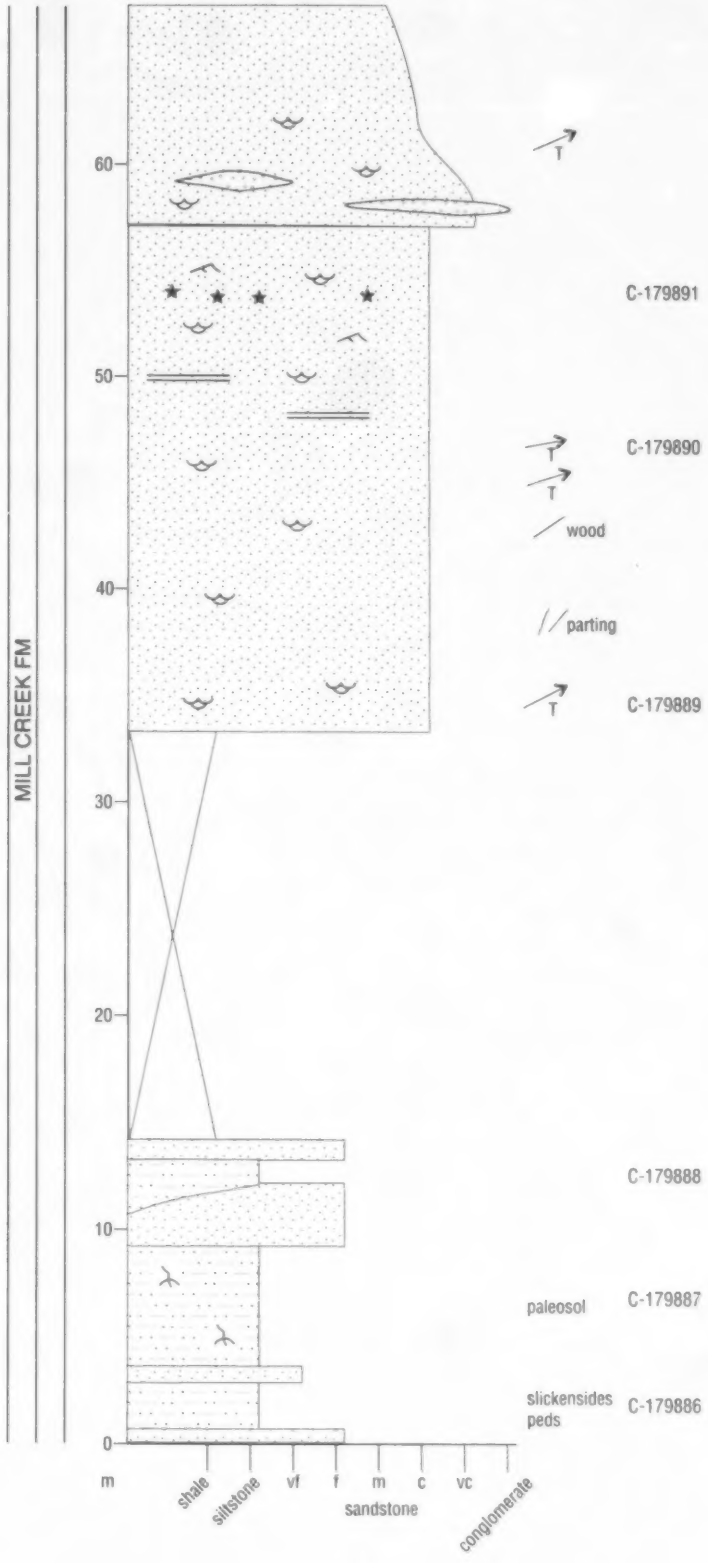
Appendix 2, Figure 3. *Mill Creek 4, Ginger Hill.*



Appendix 2, Figure 4. *Mill Creek 10, Dutch Creek.*



Appendix 2, Figure 5. *Mill Creek 11, Frank Slide Centre.*



Appendix 2, Figure 5 continued

PLATES 1–8

All figures are from unretouched negatives and prints photographed with transmitted light and interference contrast.

In the explanation of figures, the species name is followed by the GSC locality number, the slide number, Zeiss Photomicroscope co-ordinates, England Finder co-ordinates, the GSC type number with sieve size (e.g., +20 µm, un. for unsieved, -20 µm), and the magnification. All specimens are housed in the collections of the Geological Survey of Canada, 3303 33rd St. NW., Calgary, Alberta, Canada.

PLATE 1

1. *Concavissimisporites parkinii* C-178413; 178413+20; 15.8, 97.2; GSC 114805; M37-2; 660x
2. *Deltoidospora hallii* C-178424; 178424 un; 13.8, 70.9; O10-1; GSC 114806; 500x
3. *Concavissimisporites penolaensis* C-178423; 178423+20; 16.6, 82.8; L22-2; GSC 114807; 500x
4. *Concavissimisporites variverrucatus* C-178411; 178411+20; 14.6, 75.1; N14-0; GSC 114808; 660x
5. *Lophotriletes babsae* C-178413; 178413+20; 15.5, 73.3; M12-2; GSC 114809; 500x
6. *Pilosisporites brevipapillosus* C-179854; 179854+20; 15.0, 80.0; M19-4; GSC 114810; 660x
7. *Pilosisporites brevipapillosus* C-179854; 179854+20; 10.0, 81.5; R21-4; GSC 114811; 660x
8. *Pilosisporites trichopapillosus* C-178418; 178418+20; 12.6, 96.1; P36-0; GSC 114812; 500x
9. *Stoverisporites lunaris* C-179828; 179828+20; 15.8, 68.4; L7-4; GSC 114813; 500x
10. *Verrucosisporites rotundus* C-178412; 178412+20; 18.1, 97.3; J38-4; GSC 114814; 660x
11. *Cibotiidites robusta* C-178423; 178423+20; 7.6, 93.1; U33-0; GSC 114815; 500x
12. *Cibotiidites robusta* C-178423; 178423+20; 11.4, 75.6; Q15-0; GSC 114816; 500x
13. *Cicatricosisporites crassistriatus* C-178412; 178412+20; 9.7, 90.4; S30-2; GSC 114817; 500x
14. *Cicatricosisporites sp. cf. C. crassiterminatus* (proximal) C-178423; 178423+20; 8.2, 96.8; T37-3; GSC 114818; 500x
15. *Cicatricosisporites sp. cf. C. crassiterminatus* (distal) C-178423; 178423+20; 8.2, 96.8; T37-3; GSC 114819; 500x
16. *Cicatricosisporites minor* C-178412; 178412+45; 15.1, 92.1; M32-0; GSC 114820; 500x
17. *Cicatricosisporites patapscoensis* C-178412; 178412+45; 13.7, 90.3; O30-2; GSC 114821; 500x
18. *Foveotriletes subtriangularis* C-178413; 178413+20; 11.8, 81.4; Q21-1; GSC 114822; 500x
19. *Ischyosporites disjunctus* C-179860; 179860+20; 9.9, 97.5; S37-2; GSC 114823; 500x
20. *Ischyosporites punctatus* C-178407; 178407 un; 17.6, 73.6; K13-1; GSC 114824; 500x
21. *Microreticulatus uniformis* C-179856; 179856+20; 10.9, 100.3; R40-2; GSC 114825; 660x
22. *Appendicisporites cristatus* C-178431; 178431+45; 12.3, 90.0; P30-3; GSC 114826; 500x
23. *Appendicisporites matesovae* (proximal) C-178412; 178412+45; 10.2, 66.6; R6-3; GSC 114827; 500x
24. *Appendicisporites matesovae* (distal) C-178412; 178412+45; 10.2, 66.6; R6-3; GSC 114827; 500x

Plate 1

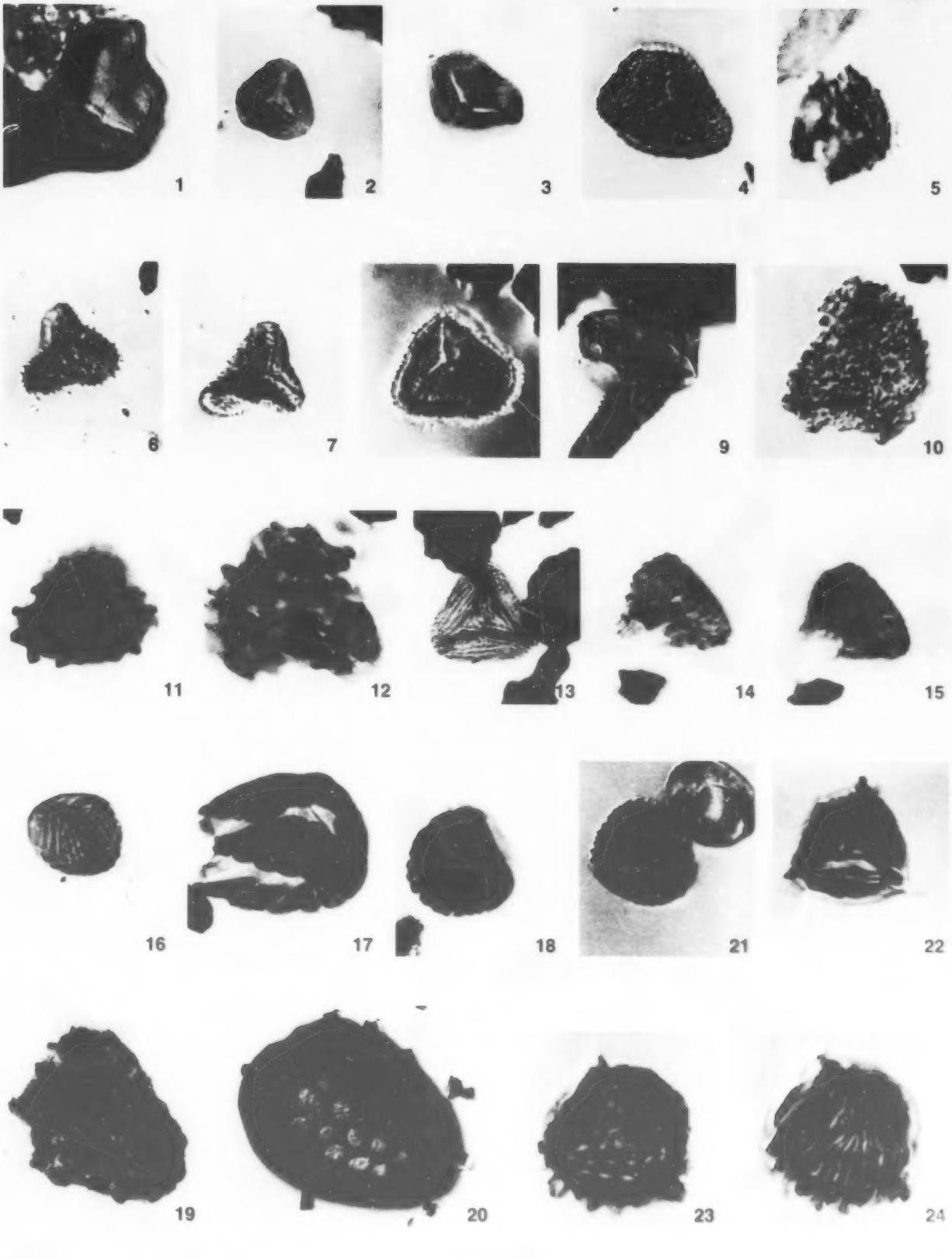


PLATE 2

1. *Appendicisporites spinosus* C-178414; 178414+45; 17.0, 85.0; K25-3; GSC 114828; 500x
2. *Appendicisporites tricostatus* C-178414; 178414+45; 17.0, 81.8; K21-4; GSC 114829; 700x
3. *Appendicisporites unicus* C-178413; 178413+20; 13.7, 95.4; 035-2; GSC 114830; 500x
4. *Impardecispora marylandensis* C-178420; 178420+20; 15.8, 87.1; L27-3; GSC 114831; 500x
5. *Camarozonotriletes ambigens* (proximal) C-179854; 179854+20; 17.8, 94.2; J34-4; GSC 114832; 750x
6. *Camarozonotriletes ambigens* (distal) C-179854; 179854+20; 17.8, 94.2; J34-4; GSC 114832; 750x
7. *Camarozonotriletes ambigens* C-178431; 178431+20; 16.6, 70.5; L10-1; GSC 114833; 500x
8. *Scopusporis spackmanii* C-178412; 178412+45; 11.8, 84.6; Q24-1; GSC 114834; 500x
9. *Contignisporites glebulentus* C-179856; 179856+20; 15.7, 93.8; M34-1; GSC 114835; 1000x
10. *Distaltriangulisporites mutabilis* C-178411; 178411+20; 13.8, 88.8; N28-4; GSC 114836; 500x
11. *Interulobites intraverrucatus* C-178426; 178426+20; 14.6, 72.0; N11-0; GSC 114837; 500x
12. *Taurocusporites segmentatus* C-178412; 178412+20; 15.8, 93.7; M34-1; GSC 114838; 660x
13. *Laevigatosporites ovatus* C-178407; 178407 un; 16.0, 75.0; L14-4; GSC 114839; 500x
14. *Triporoletes radiatus* C-178407; 178407 un; 16.5, 77.2; L16-2; GSC 114840; 500x
15. *Triporoletes reticulatus* C-178418; 178418+45; 7.3, 80.0; U19-4; GSC 114841; 500x
16. *Aequitriradites variabilis* C-179828; 179828+20; 16.2, 92.7; L33-3; GSC 114842; 1000x
17. *Aequitriradites verrucosus* C-179827; 179827+20; 7.9, 82.3; U22-1; GSC 114843; 1000x
18. *Couperisporites complexus* C-179828; 179828+20; 10.8, 67.0; R6-2; GSC 114844; 750x
19. *Januasporites spiniferus* C-178412; 178412+20; 8.1, 79.4; T19-3; GSC 114845; 500x

Plate 2

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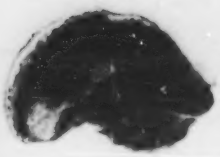
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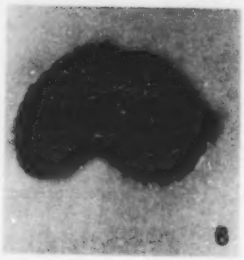
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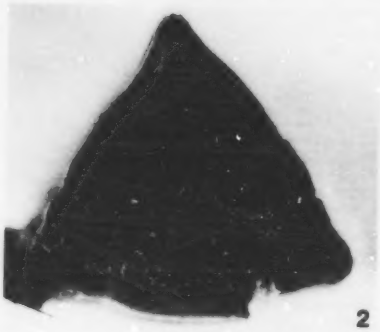
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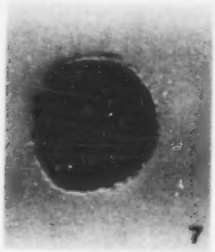
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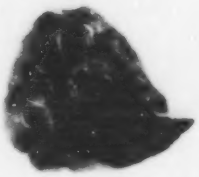
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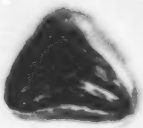
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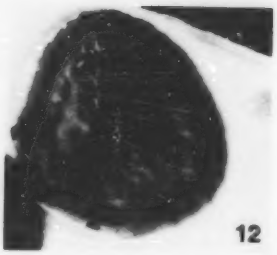
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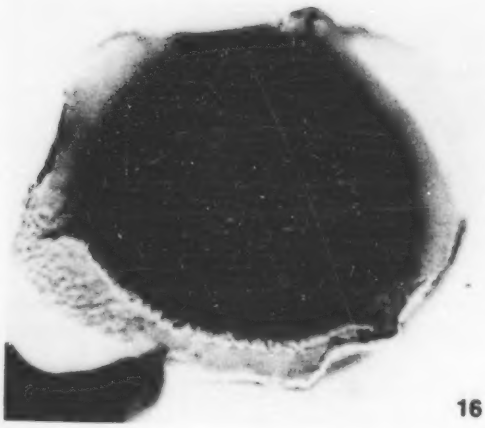
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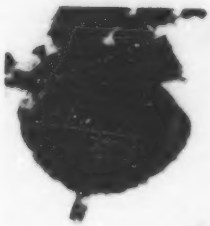
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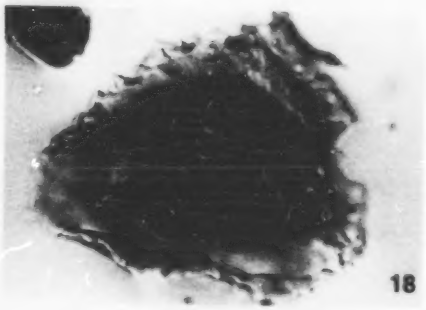
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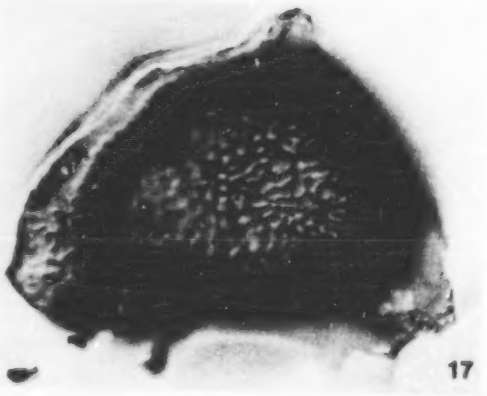
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PLATE 3

1. *Alisporites bilateralis* C-178420; 178420+45; 12.8, 88.0; P28-1; GSC 114846; 500x
2. *Alisporites bilateralis* C-178420; 178420+45; 12.6, 97.0; P37-0; GSC 114847; 500x
3. *Rugubivesiculites rugosus* C-178431; 178431+20; 14.6, 89.0; N29-1; GSC 114848; 500x
4. *Vitreisporites pallidus* C-178420; 178420+45; 7.6, 84.4; U24-0; GSC 114849; 500x
5. *Clavatipollenites hughesii* C-178414; 178414-20; 11.0, 87.4; Q27-4; GSC 114850; 1350x
6. *Clavatipollenites hughesii* C-179927; 179927-20; 74.6, 14.8; N14-1; GSC 114851; 580x
7. *Clavatipollenites minutus* C-178414; 178414-20; 14.9, 94.2; M34-4; GSC 114852; 500x
8. *Clavatipollenites tenellis* C-178411; 178411-20; 10.8, 98.1; R38-1; GSC 114853; 750x
9. *Clavatipollenites tenellis* C-178420; 178420-20; 8.7, 78.2; T18-1; GSC 114854; 1350x
10. *Liliacidites doylei* C-178414; 178414-20; 15.0, 76.9; M16-4; GSC 114855; 660x
11. *Liliacidites doylei* C-179927; 179927-20; 14.6, 89.5; N29-2; GSC 114856; 1200x
12. *Liliacidites inaequalis* C-179927; 179927-20; 8.8, 83.9; T23-2; GSC 114857; 1200x
13. *Liliacidites inaequalis* C-178414; 178414-20; 8.6, 79.4; T19-0; GSC 114858; 1200x
14. *Liliacidites tectatus* C-178424; 178424-20; 14.6, 71.2; N10-2; GSC 114859; 2000x
15. *Liliacidites* sp. D C-178407; 178407 un; 12.3, 73.6; P13-0; GSC 114860; 1200x
16. *Liliacidites* sp. E C-179828; 179828-20; 18.1, 84.8; J24-4; GSC 114861; 700x
17. *Liliacidites* sp. C-178407; 178407un; 13.3, 87.8; O27-4; GSC 114862; 1000x
18. *Racemonocolpites* sp. C-178420; 178420+45; 10.7, 87.4; R27-0; GSC 114863; 1200x
19. *Racemonocolpites* sp. C-178423; 178423+20; 10.8, 86.2; R26-1; GSC 114864; 660x
20. *Racemonocolpites* sp. C-178416; 178416-20; 12.7, 85.0; P25-1; GSC 114865; 1500x
21. *Retimonocolpites crassatus* C-178431; 178431-20; 7.9, 73.4; U13-1; GSC 114866; 1200x
22. *Retimonocolpites crassatus* C-178414; 178414-20; 15.1, 95.0; M35-0; GSC 114867; 1200x
23. *Retimonocolpites crassatus* C-178412; 178412-20; 16.9, 98.6; K39-3; GSC 114868; 1200x

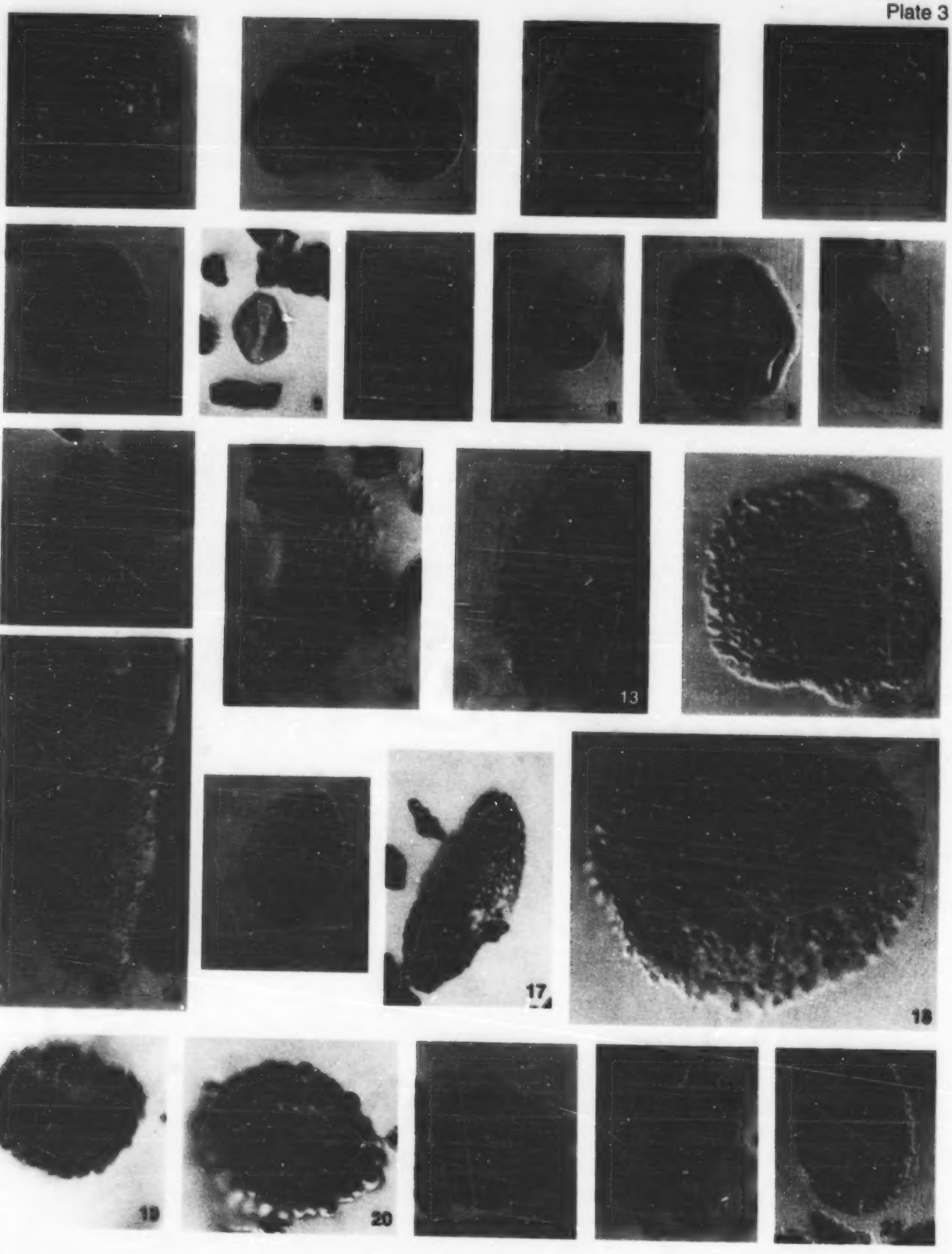
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PLATE 4

1. *Retimonocolpites dividuus* C-178411; 178411-20; 12.3, 73.9; P13-0; GSC 114869; 1000x
2. *Retimonocolpites dividuus* C-178416; 178416-20; 16.5, 78.2; L18-1; GSC 114870; 1250x
3. *Retimonocolpites peroreticulatus* C-178927; 179927-20; 12.7, 80.0; P19-2; GSC 114871; 2000x
4. *Retimonocolpites peroreticulatus* C-179927; 179927-20; 11.7, 86.1; Q26-1; GSC 114872; 2000x
5. *Retimonocolpites peroreticulatus* (distal - colp) C-178927; 179927-20; 18.4, 98.3; J38-2; GSC 114873; 2000x
6. *Retimonocolpites peroreticulatus* (proximal) C-178927; 179927-20; 18.4, 98.3; J38-2; GSC 114873; 2000x
7. *Retimonocolpites reticulatus* C-179973; 179927-20; 11.0, 83.1; Q23-3; GSC 114874; 2000x
8. *Retimonocolpites textus* C-179850; 179850-20; 16.0, 84.2; L24-3; GSC 114875; 1000x
9. *Retimonocolpites textus* C-179927; 179927-20; 9.0, 90.0; T30-1; GSC 114876; 1000x
10. *Asteropollis asteroides* C-178413; 178413-20; 7.9, 98.9; U39-1; GSC 114877; 1000x
11. *Asteropollis trichotomosulcatus* C-179927; 179927-20; 7.8, 95.9; U36-0; GSC 114878; 1000x
12. *Asteropollis trichotomosulcatus* C-178413; 178413-20; 8.8, 80.8; T20-2; GSC 114879; 660x
13. *Cupuliferoidaepollenites parvulus* C-178418; 178418-20; 9.9, 66.6; S6-1; GSC 114880; 1000x
14. *Cupuliferoidaepollenites parvulus* C-179830; 179830-20; 17.2, 84.5; K24-0; GSC 114881; 1000x
15. *Foveotricolpites concinnus* C-179927; 179927-20; 12.6, 88.4; P28-0; GSC 114882; 1000x
16. *Foveotricolpites concinnus* C-178423; 178423-20; 9.5, 94.6; S34-2; GSC 114883; 1000x
17. *Phimopollenites augathellaensis* C-179927; 179927-20; 16.9, 71.2; K10-4; GSC 114884; 1000x
18. *Phimopollenites augathellaensis* C-179927; 179927-20; 22.1, 76.0; E15-0; GSC 114885; 1000x
19. *Phimopollenites pannosus* C-179927; 179927-20; 17.9, 68.0; J7-0; GSC 114886; 2000x
20. *Phimopollenites pannosus* C-179927; 179927-20; 17.0, 96.5; K37-3; GSC 114887; 2000x
21. *Retitrescolpites kempiae* C-179927; 179927-20; 15.0, 67.8; M7-3; GSC 114888; 1000x
22. *Retitrescolpites maximus* C-178407; 178407 un; 8.0, 88.3; U28-2; GSC 114889; 1000x
23. *Retitrescolpites maximus* C-178407; 178407 un; 14.3, 78.3; N18-3; GSC 114890; 1000x
24. *Retitrescolpites vermimurus* (polar) C-179830; 179830-20; 18.2, 71.3; J10-4; GSC 114891; 2000x
25. *Retitrescolpites vermimurus* (equatorial) C-179830; 179830-20; 18.2, 71.3; J10-4; GSC 114891; 2000x
26. *Retitrescolpites vermimurus* C-179927; 179927-20; 18.0, 97.7; J38-0; GSC 114892; 2000x
27. *Retitrescolpites virgeus* (polar) C-178414; 178414-20; 11.5, 84.8; Q24-0; GSC 114893; 2000x
28. *Retitrescolpites virgeus* (equatorial) C-178414; 178414-20; 11.5, 84.8; Q24-0; GSC 114893; 2000x
29. *Retitrescolpites virgeus* C-178413; 178413-20; 18.0, 89.5; J29-4; GSC 114894; 1000x

Plate 4

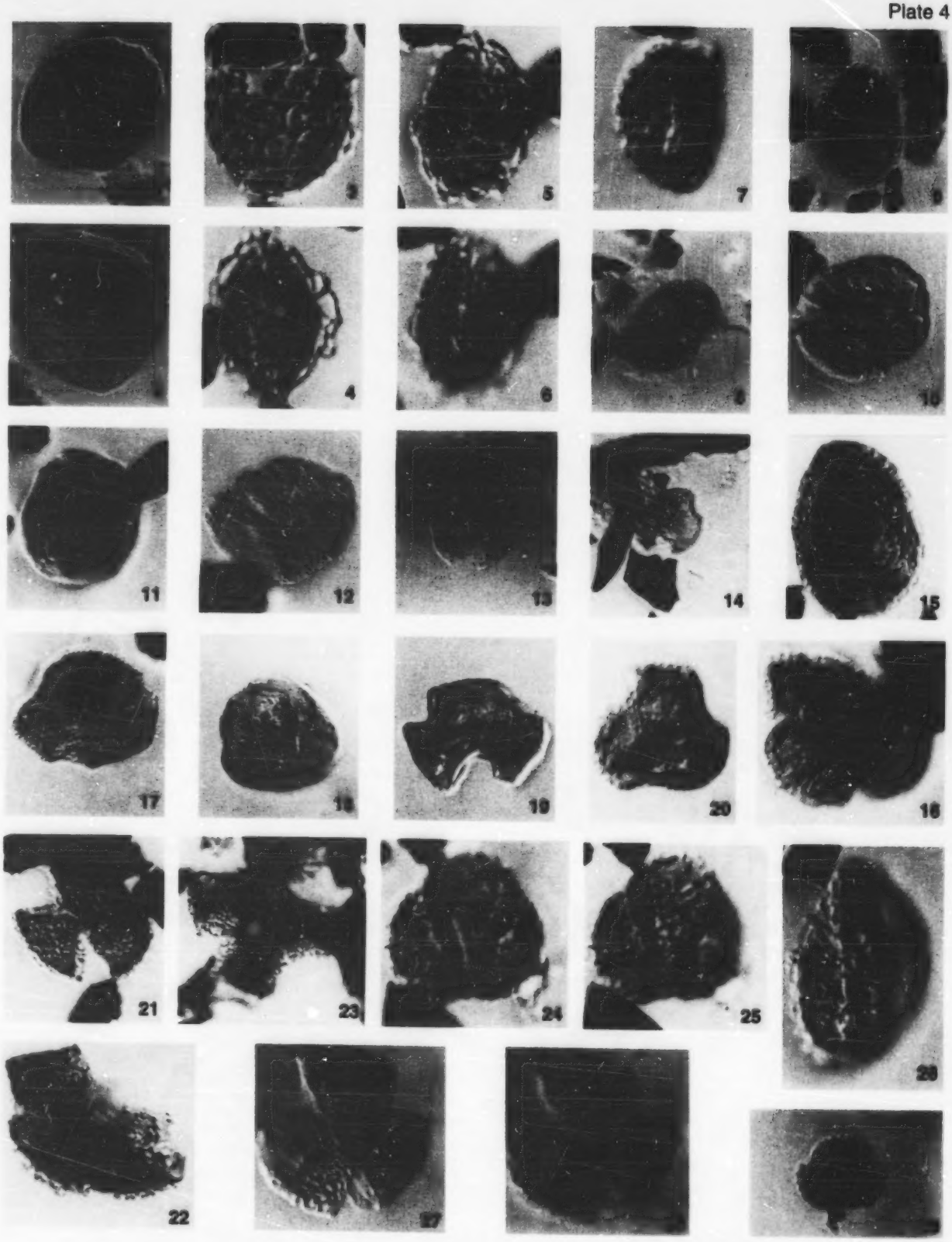

PLATE 5

1. *Rousea brenneri* C-179927; 179927-20; 22.6, 82.4; E22-1; GSC 114895; 1200x
2. *Rousea brenneri* C-179927; 179927-20; 22.6, 82.4; E22-1; GSC 114895; 1200x
3. *Rousea brenneri* C-179927; 179927+20; 10.8, 89.8; R29-2; GSC 114896; 1000x
4. *Rousea brenneri* C-179927; 179927+20; 15.9, 68.0; M7-1; GSC 114897; 1000x
5. *Rousea brenneri* C-179927; 179927+20; 10.7, 97.3; R37-2; GSC 114898; 660x
6. *Rousea brenneri* C-179927; 179927-20; 11.8, 85.0; Q25-1; GSC 114899; 660x
7. *Rousea georgensis* C-178407; 178407 un; 14.5, 100.0; N40-0; GSC 114900; 1800x
8. *Rousea georgensis* C-179927; 179927-20; 9.0, 64.9; T4-1; GSC 114901; 1250x
9. *Rousea georgensis* C-179927; 179927-20; 12.9, 79.3; P19-1; GSC 114902; 1000x
10. *Rousea georgensis* C-178414; 178414-20; 11.0, 95.8; Q36-3; GSC 114903; 1000x
11. *Rousea marthae* C-179927; 179927-20; 21.0, 92.6; F33-3; GSC 114904; 1700x
12. *Rousea marthae* C-179927; 179927-20; 21.0, 92.6; F33-3; GSC 114904; 1700x
13. *Rousea miculipollis* C-178414; 178414-20; 17.8, 85.1; K25-1; GSC 114905; 2000x
14. *Rousea prosimilis* C-179927; 179927-20; 16.3, 65.7; L5-0; GSC 114906; 1700x
15. *Rousea prosimilis* C-179927; 179927-20; 13.7, 77.3; O16-2; GSC 114907; 1700x
16. *Rousea prosimilis* C-179828; 179828-20; 12.8, 69.3; P8-2; GSC 114908; 1700x
17. *Striatopollis paranea* C-179927; 179927-20; 19.6 88.7; H28-2; GSC 114909; 2000x
18. *Striatopollis paranea* C-179927; 179927-20; 19.6 88.7; H28-2; GSC 1149909; 2000x
19. *Striatopollis* sp. C-179830; 179830-20; 9.1, 72.9; S12-4; GSC 114910; 2000x
20. *Striatopollis* sp. C-179830; 179830-20; 12.9, 88.5; O28-4; GSC 114911; 2000x
21. *Tricolpites crassimurus* C-178409; 178409 un; 12.4, 88.4; P28-0; GSC 114912; 1000x
22. *Tricolpites crassimurus* C-178414; 178414+45; 5.9, 84.3; W24-1; GSC 114913; 1000x
23. *Tricolpites crassimurus* C-179927; 179927+20; 15.8, 73.5; M13-1; GSC 114914; 1000x

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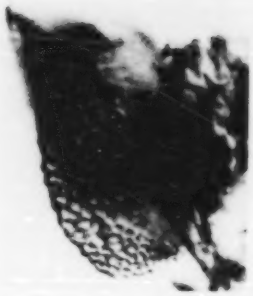

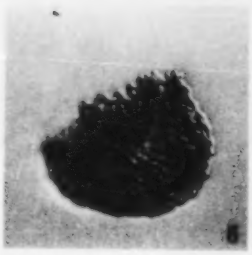
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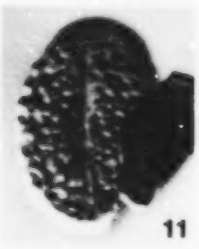
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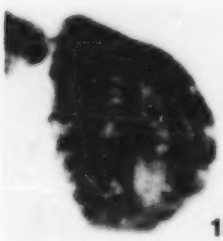
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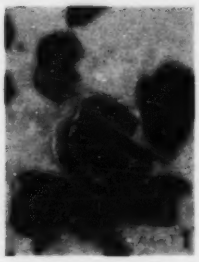
PLATE 6

1. *Tricolpites fragosus* C-179830; 179830-20; 8.7, 82.3; T22-0; GSC 114915; 1000x
2. *Tricolpites fragosus* C-179861; 179861+20; 16.9, 97.6; K38-3; GSC 114916; 750x
3. *Tricolpites micromunus* C-178411; 178411-20; 8.2, 77.3; T17-3; GSC 114917; 1500x
4. *Tricolpites micromunus* C-178414; 178414-20; 11.0, 83.6; Q23-3; GSC 114918; 2000x
5. *Tricolpites micromunus* C-178414; 178414-20; 17.9, 86.4; J26-4; GSC 114919; 2000x
6. *Tricolpites parvus* C-178412; 178412-20; 17.6, 67.9; K7-1; GSC 114920; 2000x
7. *Tricolpites parvus* C-178412; 178412-20; 9.0, 101.1; T41-2; GSC 114921; 2000x
8. *Tricolpites sagax* C-179830; 179830-20; 14.6, 69.3; N8-2; GSC 114922; 2000x
9. *Tricolpites sagax* C-178431; 178431-20; 14.7, 94.3; N34-2; GSC 114923; 2000x
10. *Tricolpites vulgaris* C-178412; 178412-20; 12.5, 80.9; P20-2; GSC 114924; 1000x
11. *Tricolpites vulgaris* C-178413; 178413-20; 11.0, 87.2; Q27-3; GSC 114925; 1000x
12. *Tricolpites vulgaris* C-179850; 179850-20; 15.1, 85.9; M25-4; GSC 114926; 1000x
13. *Tricolpites vulgaris* C-179850; 179850-20; 12.9, 74.5; P14-1; GSC 114927; 1000x
14. *Ajatipollis* sp. A of Doyle and Robbins 1977 C-179828; 179828+20; 13.1, 93.2; O33-0; GSC 114928; 1000x
15. *Senecotetradites amiantopollis* C-178431; 178431-20; 9.9, 90.3; R30-4; GSC 114929; 2000x
16. *Senecotetradites varireticulatus* C-178431; 178431-20; 8.0, 90.9; U31-1; GSC 114930; 1000x
17. *Penetetrapites mollis* C-178414; 178414-20; 10.0, 93.2; R33-4; GSC 114931; 2000x
18. *Quadricolpites reticulatus* C-178413; 178413 un; 12.6, 91.7; P32-1; GSC 114932; 1200x
19. *Tricolporoidites* sp. C-179927; 179927-20; 16.3, 64.3; L3-0; GSC 114933; 1700x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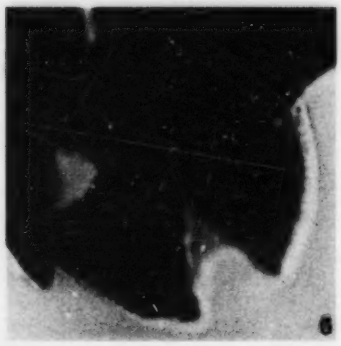
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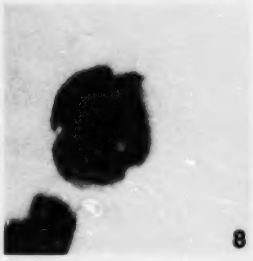
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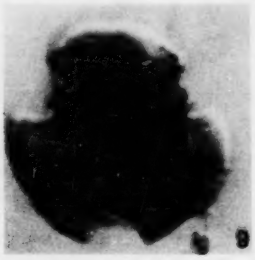
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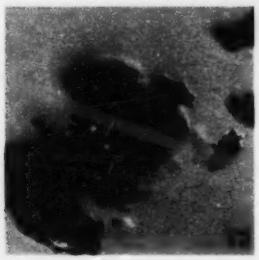

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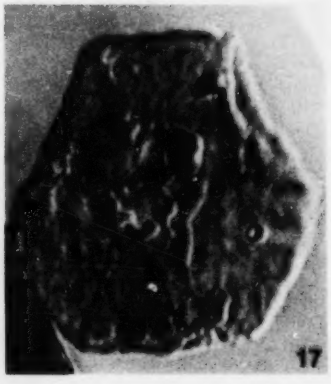
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PLATE 7

1. *Dyadosporites ellipsus* C-178411; 178411-20; 13.9, 101.2; N41-4; GSC 114934; 500x
2. *Dyadosporites* sp. 1 C-178420; 178420-20; 16.9, 98.6; K39-3; GSC 114935; 500x
3. *Dyadosporites* sp. 2 C-178411; 178411-20; 8.8, 82.5; T22-1; GSC 114936; 500x
4. *Pluricellaesporites psilatus* C-178420; 178420-20; 12.8, 93.7; P34-1; GSC 114937; 500x
5. Fungal Hyphae form 1 C-178412; 178412-20; 18.1, 96.6; J37-3; GSC 114938; 1250x
6. Fungal Hyphae form 2 C-178412; 178412-20; 17.8, 96.8; J37-3; GSC 114939; 1250x
7. Fungal tetrad C-178412; 178412-20; 7.6, 82.6; U22-0: GSC 114940; 1000x
8. *Balmula tripenta* C-178420; 178420+45; 12.8, 102.0; P42-2; GSC 114941; 500x
9. *Balmula tripenta* C-178409; 178409+45; 18.2, 73.5; J13-3; GSC 114942; 500x
10. *Nyktericysta davisii* C-178411; 178411+20; 10.7, 102.5; R43-1; GSC 114943; 660x
11. *Nyktericysta davisii* C-178420; 178420+20; 11.8, 70.1; Q9-2; GSC 114944; 660x
12. *Nyktericysta davisii* C-178409; 178409+45; 12.8, 95.5; P35-2; GSC 114945; 500x
13. *Odontochitina singhii* C-178431; 178431+45; 11.2, 67.4; Q6-4; GSC 114946; 600x
14. *Pseudoceratium interiorense* C-178409; 178409+45; 15.0, 85.1; M25-3; GSC 114947; 600x
15. *Hurlandsia* sp. cf. *H. rugarum* C-178423; 178423-20; 9.6, 91.7; S31-2; GSC 114948; 600x
16. *Hurlandsia* sp. cf. *H. rugarum* C-178409; 178409+45; 8.0, 76.9; T16-4; GSC 114949; 600x
17. *Hurlandsia* sp. cf. *H. rugarum* C-178423; 178423+20; 17.8, 74.0; J13-4; GSC 114950; 600x

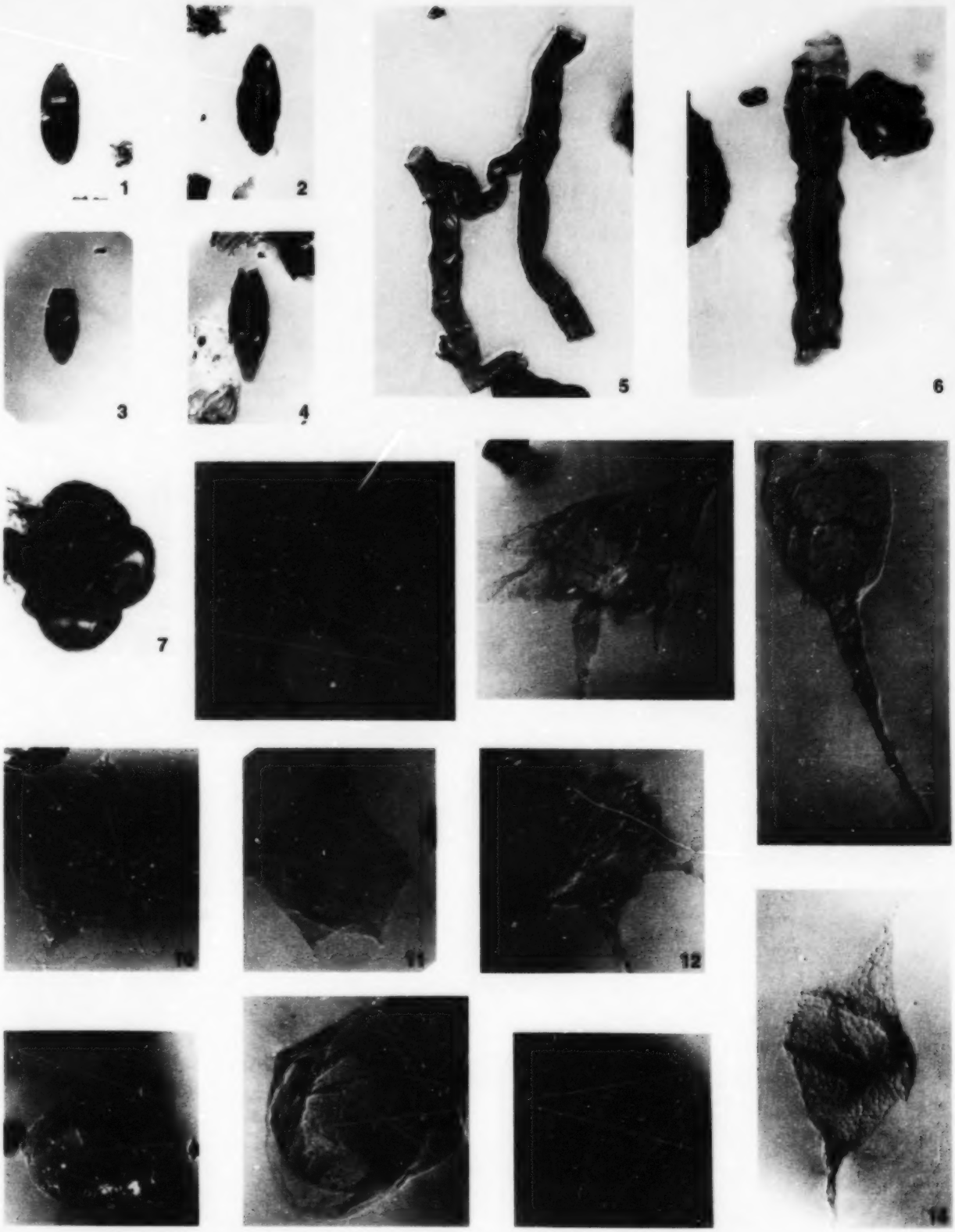
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PLATE 8

1. *Wigginsiella canadense* C-178431; 178431+20; 16.1, 91.9; L32-3; GSC 114951; 550x
2. *Oligosphaeridium pulcherrimum* C-178431; 178431+45; 17.5, 100.2; K40-2; GSC 114952; 550x
3. *Cleistosphaeridium multispinosum* C-178431; 178431+45; 10.6, 74.2; R13-2; GSC 114953; 550x
4. *Wallodinium bidigitatum* C-178431; 178431+20; 14.8, 97.1; N37-2; GSC 114954; 550x
5. *Chlamydophorella nyei* C-178431; 178431+45; 12.3, 70.1; P9-0; GSC 114955; 550x
6. *Laciniadinium arcticum* C-178411; 178411+20; 15.7, 76.3; M15-2; GSC 114956; 550x
7. *Subtilisphaera pirnaensis* C-178431; 178431+45; 16.7, 87.3; L27-1; GSC 114957; 550x
8. *Fromea amphora* C-178431; 178431+45; 10.6, 82.4; R22-0; GSC 114958; 550x
9. *Fromea* sp. cf. *F. fragilis* C-178411; 178411+20; 9.7, 102.0; S42-0; GSC 114959; 550x
10. *Fromea* sp. cf. *F. fragilis* C-178420; 178420+20; 11.6, 70.2; Q9-2; GSC 114960; 550x
11. *Tetraedron* sp. C-178411; 178411-20; 15.9, 73.4; L12-4; GSC 114961; 750x
12. *Pediastrum* sp. C-178411; 178411-20; 18.0, 100.7; J41-0; GSC 114962; 1250x
13. *Scenedesmus* sp. C-178412; 178412+20; 14.7, 69.3; N8-2; GSC 114963; 1000x
14. *Scenedesmus* sp. C-178412; 178412+45; 10.9, 84.4; Q24-3; GSC 114964; 500x
15. *Schizophacus* sp. C-178423; 178423+20; 12.3, 88.0; P28-3; GSC 114965; 500x
16. *Tetranguladinium conspicuum* C-178407; 178407 un; 16.1, 90.2; L30-0; GSC 114966; 660x
17. *Tetraporina horologia* C-178414; 178414-20; 11.6, 69.7; Q9-0; GSC 114967; 1250x
18. *Chomotriletes minor* C-178412; 178412+20; 8.9, 93.7; T34-1; GSC 114968; 1250x
19. *Tasmanites* sp. C-178409; 178409+45; 14.6, 75.5; N15-1; GSC 114969; 500x
20. *Pterospermella harti* C-178423; 178423-20; 17.6, 95.0; K35-1; GSC 114970; 1500x
21. *Micrhystridium* sp. C-178411; 178411-20; 8.9, 102.4; T43-1; GSC 114971; 1000x
22. *Veryhachium rhomboidium* C-178423; 178423-20; 10.9, 72.4; Q12-3; GSC 114972; 660x
23. *Lecaniella foveata* C-178412; 178412+45; 16.5, 99.6; L40-1; GSC 114973; 500x